Tinker Air Force Base
Industrial Wastewater Treatment Plant/
Soldier Creek Off-Base Groundwater
Operable Units

Feasibility Study
Draft Final

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6. AUTHOR(S)
C. Vail, K. Rice, J.Yu, J. Burdey

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)
Parsons Engineering Science, Inc.
8000 Centre Park Drive, Suite 200
Austin, TX 78754-5140

8. PERFORMING ORGANIZATION REPORT NUMBER
Parsons ES 721447

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
James Dawson
OC-ALC/EMR
7701 Second Street, Suite 214
Tinker AFB, OK 73145-9100

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13. ABSTRACT (Maximum 200 words)

This report presents findings of a feasibility study (FS) conducted for the Industrial Wastewater Treatment Plant/ Soldier Creek Off-Base Groundwater Operable Units at Tinker AFB. The FS addresses groundwater contamination on the base and in the area northeast of the base. The conceptual model presented in the Remedial Investigation Report identified a lower saturated zone (LSZ) groundwater divide in the northeast corner of the base. The risk assessment identified vinyl chloride as contaminant contributing to risk south of the divide. North of the divide, thallium contributed to risk. However, thallium contamination is not considered base related, therefore, will not be remediated. This FS addresses the areas north of the divide and south of the divide separately. North of the divide the no action alternative was recommended. South of the divide, the alternative recommended includes installation of five extraction wells, and upgrade and use of the Building 3001 groundwater treatment plant to handle vinyl chloride. Treated water would then go to an industrial reuse system.

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ACRONYMS & ABBREVIATIONS

ACL	Alternate concentration limits
AFB	Air Force Base
AOC	Area of concern
ARARs	Applicable or relevant and appropriate requirements
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
B&V	Black & Veatch
BGL	Below ground level
BNA	Bureau of National Affairs
BTEX	Benzene, toluene, ethyl benzene, and xylenes
CAA	Clean Air Act
CAS	Carbon adsorption system
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CT	Central tendency
CWA	Clean Water Act
1,2-DCA	1,2-Dichloroethane
DCA	Dichloroethane
DCE	Dichloroethene
DERP	Defense Environmental Restoration Program
DNAPL	Dense non-aqueous phase liquid
DOD	Department of Defense
EPA	U.S. Environmental Protection Agency
FFA	Federal Facilities Agreement
FS	Feasibility Study
gpd	Gallons per day
gpm	Gallons per minute
G-W	Garber-Wellington
GWTP	Groundwater Treatment Plant
HI	Hazard index
HWM	Hazardous waste management
IDL	Instrument detection limit
IDW	Investigation derived waste
IRP	Installation Restoration Program
IWTP	Industrial Wastewater Treatment Plant

K	Hydraulic Conductivity
LDR	Land disposal restrictions
LNAPL	Light non-aqueous phase liquid
LOD	Limit of detection
LSZ	Lower saturated zone
LTM	Long term monitoring
MCLs	Maximum contaminant levels
MCLG	Maximum contaminant level goal
MDL	Method detection limit
MGD	Million gallons per day
mg/L	Milligrams per liter
mL	Milliliter
mph	Miles per hour
MTV	Mobility, toxicity, and volume
MW	Monitoring well
NAAQS	National Ambient Air Quality Standards
NAS	National Academy of Sciences
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
NESHAPS	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NTA	North Tank Area
O&M	Operation and maintenance
OAC	Oklahoma Administrative Code
OC-ALC	Oklahoma City Air Logistics Center
ODEQ	Oklahoma Department of Environmental Quality
OSDH	Oklahoma State Department of Health
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
OUs	Operable Units
P&T	Pump-and-treat
Parsons ES	Parsons Engineering Science, Inc.
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
PCE	Tetrachloroethene
POTW	Public owned treatment works
PP	Proposed Plan
PRGs	Preliminary remediation goals
PZ	Production Zone

QA	Quality assurance
QAPP	Quality assurance project plan
QC	Quality control
RA	Risk Assessment
RAO	Remedial action objective
RCRA	Resource Conservation and Recovery Act
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RI/FS	Remedial Investigation and Feasibility Study
RME	Reasonable maximum exposure
ROD	Record of Decision
SARA	Superfund Amendments and Reauthorization Act
SCOBGW	Soldier Creek Off-Base Groundwater
SDWA	Safe Drinking Water Act
SIP	State implementation plan
SMCL	Secondary maximum contaminant levels
SOW	Statement of Work
SVOC	Semivolatile organic compound
SWMUs	Solid waste management units
SWTP	Sanitary wastewater treatment plant
TAC	Tactical Air Command
TAFB	Tinker Air Force Base
TBC	To be considered
TCA	Trichloroethane
TCE	Trichloroethene
TCL	Target compound list
TCLP	Toxicity characteristic leaching procedure
TEGD	Technical Enforcement Guidance Document
TOC	Top of casing
TSCA	Toxic Substances Control Act
USACE	U.S. Army Corps of Engineers
USAF	United States Air Force
USC	United States Code
USGS	United States Geological Survey
UST	Underground storage tank
USZ	Upper saturated zone
UV	Ultraviolet
VC	Vinyl chloride
VOC	Volatile organic compound

WWTF	Wastewater Treatment Facility
yd^3	Cubic yards
°C	Degrees Celsius
°F	Degrees Fahrenheit
μ	Micron
μg/L	Microgram per liter

SECTION 1

INTRODUCTION

1.1 PURPOSE OF REPORT

A feasibility study (FS) was conducted for the Industrial Wastewater Treatment Plant/Soldier Creek Off-Base Groundwater Operable Units (hereafter referred to as the IWTP/SCOBGW OUs) at Tinker Air Force Base (AFB), Oklahoma. This report presents the review of the alternatives investigated to remediate those portions of the IWTP/SCOBGW OUs which pose an unacceptable risk to human health or the environment. This work was performed by Parsons Engineering Science (Parsons ES) under contract to the Oklahoma City Air Logistics Center (OC-ALC) at Tinker AFB, Oklahoma. This report is a product of the Air Force Installation Restoration Program (IRP).

1.2 REGULATORY BASIS

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 established the Defense Environmental Restoration Program (DERP) for the U.S. Department of Defense (DOD) to clean up past hazardous waste disposal and spill sites nationwide. In 1980, the United States Air Force (USAF) began implementing the DOD IRP. The IRP is designed to identify and evaluate suspected problems associated with past hazardous waste management practices, and to control hazards to human health and the environment resulting from past operations.

Section 105 of SARA mandates that procedures for undertaking response actions follow the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) as promulgated by the U.S. Environmental Protection Agency (EPA). To be consistent with SARA, the USAF (1989) decided that all future work will follow EPA guidance for conducting remedial investigations and feasibility studies (RI/FS) (EPA, 1988c). The objectives of the RI efforts are to acquire data to confirm and quantify environmental contamination. These data are used to support follow-up activities, if required, and subsequent remediation. The RI may require several stages to adequately define a site and produce data for the FS.

Tinker AFB, U.S. EPA Region VI, and the Oklahoma State Department of Health (OSDH) signed a Federal Facilities Agreement (FFA) (Administrative Docket Number NPL-U3-2-27) under CERCLA in December 1988. The intent of this agreement is to ensure that past and present activities at Building 3001 and Soldier Creek National Priorities List (NPL) site are thoroughly investigated and appropriately remediated to protect the public health, welfare, and the environment. The FFA also establishes requirements for the performance of the RI/FS in accordance with CERCLA.

1.3 PROJECT AUTHORIZATION

Parsons ES was contracted by OC-ALC to perform a feasibility study at the IWTP/SCOBGW OUs under contract number F34650-93-D-0106, delivery order number 5001. Work performed for delivery order 5001 is defined in the statement of work (SOW). Notice for Parsons ES to proceed with work defined in the SOW was issued on August 25, 1993. During the course of the project, the scope of work has been revised to meet data and regulatory needs.

1.4 OBJECTIVES AND SCOPE

The focus of this FS is remediation of groundwater contamination in the northeast quadrant of Tinker AFB and privately-owned lands to the north and east of the base. Building 3001, the industrial wastewater treatment plant (IWTP), and East Soldier Creek are located in the northeast portion of the base and have all been identified as possible sources of groundwater contamination in the area. The purpose of this FS is to review potentially applicable treatment technologies and recommend a remediation program.

A remedial investigation was performed to provide a detailed conceptual model of the geology, hydrogeology, and hydrology of the area. In addition, the nature and extent of groundwater contamination were characterized. The results of the investigation are documented in the Remedial Investigation Report (Parsons ES, 1998). Based upon the results of the remedial investigation, a risk assessment was performed (Parsons ES, 2000). The results of this baseline risk assessment are described in Section 2.

1.5 REPORT ORGANIZATION

This report describes findings and conclusions of the FS. The baseline risk assessment, which describes receptors and assesses the potential for contaminant migration to potential exposure points and the receptors, is being submitted as a separate report (Parsons ES, 2000).

Section 1 of this report is the introduction describing the purpose of this report, the regulatory basis for the study, the contract authorization, and the objectives and scope of work.

Section 2 describes the background and environmental settings of Tinker AFB. This section also summarizes results of previous investigations and provides a brief description of current studies.

Section 3 presents the applicable or relevant and appropriate requirements (ARARs) and develops the remedial action objectives (RAOs), the preliminary remediation goals (PRGs), and the alternate concentration limits (ACLs).

Section 4 presents the preliminary screening of treatment technologies. Alternatives are developed and screened in Section 5. Section 6 provides a detailed evaluation of alternatives, and Section 7 presents conclusions and recommendations.

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SECTION 2

ENVIRONMENTAL SETTING AND SITE HISTORY

Information regarding environmental setting and site history relevant to the feasibility study is presented in this section. Previous investigations (Parsons ES, 1998) have identified contaminants of concern, plume locations and sizes, and physical characteristics of the water-bearing zones underlying the base. These data on the physical and chemical characteristics of the plume are used in the FS to determine feasible treatment options. Information presented in the draft IWTP/SCOBGW OUs risk assessment (Parsons ES, 2000) identifying contaminants contributing to human health and risk exposure pathways is used to determine preliminary remediation goals (PRGs) in the FS. Thus, this section provides a summary of the information used in determining cleanup criteria and feasible treatment technologies.

2.1 INSTALLATION AND SITE DESCRIPTION

This section presents a summary of the environmental setting and site history of Tinker AFB. An extensive description of the investigations at Tinker AFB can be found in the Remedial Investigation Report (Parsons ES, 1998).

Tinker AFB is a U.S. Air Force (USAF) installation located in Oklahoma County in central Oklahoma, approximately 8 miles southeast of downtown Oklahoma City. Figure 2.1 shows the location of Tinker AFB. The base comprises 5,277 acres and is bounded by Interstate 40 to the north, Douglas Boulevard to the east, Southeast 74th Street to the south, and Sooner Road to the west. The base is in the southeast portion of the Oklahoma City metropolitan complex, surrounded by Midwest City on the north, Del City on the northwest, and Oklahoma City on the east, south, and southwest. Oklahoma City is also north of Midwest City and Del City, which are heavily populated commercial and residential districts.

The base is located in the Great Plains where the climate is temperate and precipitation averages 33.8 inches per year. Winds in the Oklahoma City area are variable, prevailing from the south-southeast at an average wind speed of 12.4 miles per hour. The average temperature is 60.1 degrees Fahrenheit.

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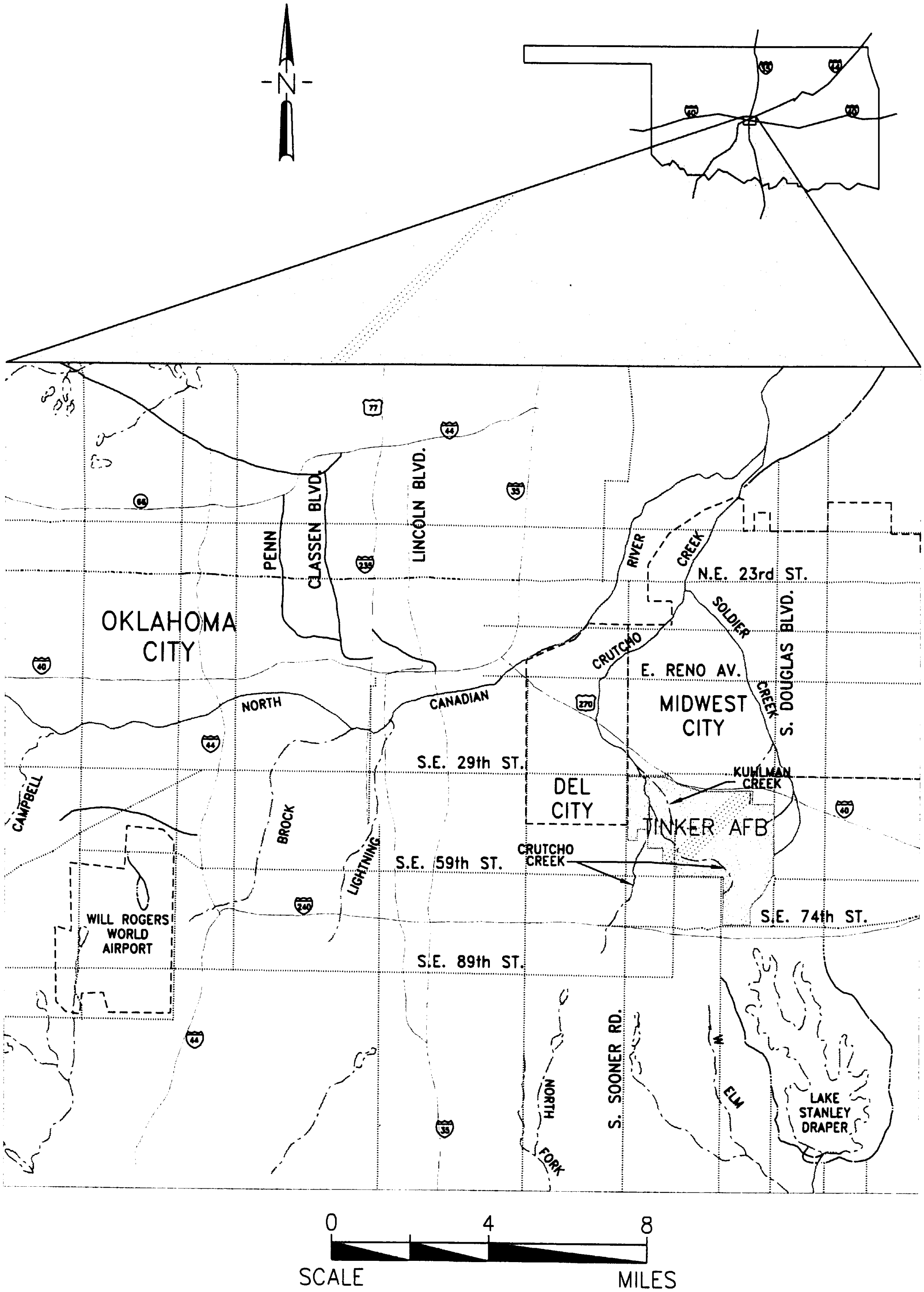

LEGEND
HIGHWAY OR INTERSTATE
MAJOR ROAD
RIVER OR CREEK

SOURCE: BLACK & VEATCH, 1993, MODIFIED

Figure 2.1
Tinker Air Force Base
Location Map
IWTP/SCOBGW OUs
Feasibility Study
Tinker AFB, Oklahoma

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Area topography is characterized by gently rolling hills, broad flat plains, and well entrenched streams. The IWTP/SCOBGW OUs lie within the conceptual model area which occupies approximately 960 acres of relatively flat uplands dissected by Soldier Creek and its tributaries. Boundaries of the conceptual model area, the IWTP/SCOBGW OUs, and area included in the risk assessment are shown on Figure 2.2. The IWTP/SCOBGW OUs underlie an area bounded by East Soldier Creek on the east and southeast, West Soldier Creek (and its tributaries) on the west, Interstate 40 on the north, and Southeast 44th Street on the south of Building 3001. The conceptual model area extends north, east, and west of the IWTP/SCOBGW Ous; the north boundary is at the confluence of main Soldier Creek and West Soldier Creek; the east boundary is at the confluence of main Soldier Creek and East Soldier Creek; and the west boundary parallels the east edge of the main runway at Tinker AFB. Soldier Creek and its tributaries receive surface runoff or discharge from approximately 9,000 acres above its confluence with Crutcho Creek, which includes the Building 3001 complex, the IWTP, and the eastern-most runway areas.

2.2 CURRENT AND HISTORICAL EVIDENCE OF CONTAMINATION

2.2.1 Building 3001

The Building 3001/Soldier Creek NPL site is located near the northeast boundary of the base, covering approximately 220 acres. Building 3001 includes the building complex, the North Tank Area (NTA), Pit Q-51, and surrounding areas encompassed by the lateral extent of a contaminant plume originating from Building 3001. Since building operations began in the 1940s, industrial activities primarily included aircraft and jet engine service, repair, and overhaul. Organic solvents were used to clean and degrease metal engine parts. Trichloroethene (TCE) was the predominant solvent used from the 1940s to the 1970s. Tetrachloroethene (PCE) was used in the 1970s. Wastewater from plating and paint-stripping operations contained solvents; wastewater from heat-treating activities contained solvents and metals. Subsurface contamination occurred primarily by leakage from pits and trenches, improper discharge to storm drains, accidental spills, and/or improper connections between wastewater and storm drains. At the NTA, soil and groundwater contamination occurred due to leaking tanks and/or possible spills. Leaking utility lines in the area may have also contaminated groundwater with organic solvents and metals. Pit Q-51 also contained hazardous contaminants. TCE and chromium are considered the primary groundwater contaminants at the Building 3001 site. Other significant contaminants included dichloroethene (DCE), PCE, acetone, toluene, benzene, xylenes, barium, lead, and nickel.

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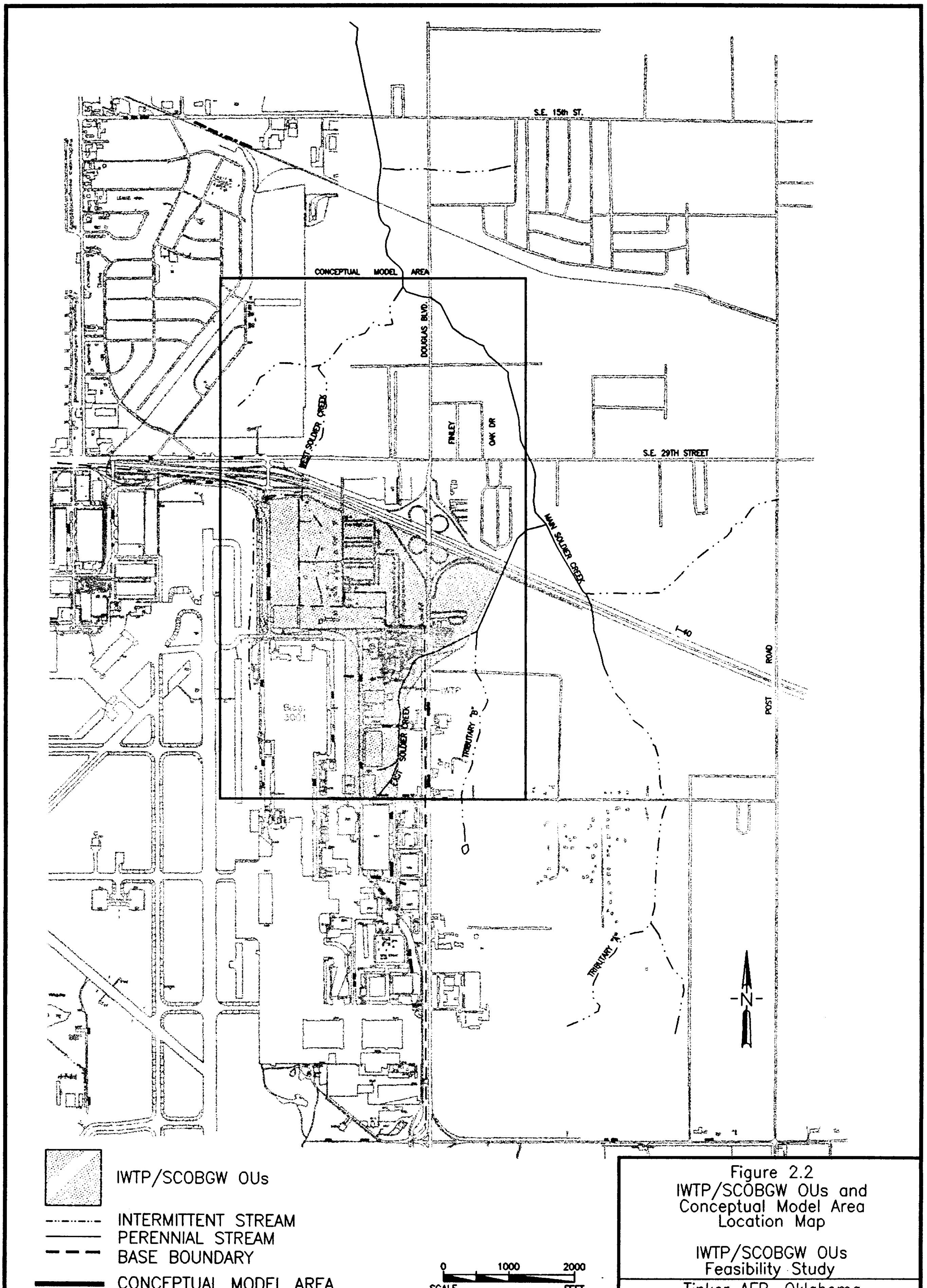

Figure 2.2
IWTP/SCOBGW OUs and Conceptual Model Area Location Map

IWTP/SCOBGW OUs Feasibility Study

Tinker AFB, Oklahoma

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Extensive investigations were conducted to determine the nature and extent of contamination in and around the Building 3001 complex. The RI report (Parsons ES, 1998) provides a review of these investigations. Remarks on a few of these investigations are included below.

The Building 3001 site was added to the NPL in 1987. A record of decision (ROD) was signed in August 1990 which included provisions for a groundwater treatment system (USACE, 1990). The treatment system was installed and includes thirty-three extraction and containment wells (five horizontal wells and twenty-eight vertical wells). The horizontal wells are primarily for extraction of contamination below Building 3001; the vertical wells are located around the building and are primarily for containment of contamination. The recovery system began intermittent pumping in February 1993 and continuous pumping in June 1994.

A public health assessment for the Building 3001/Soldier Creek site was released in 1995 by the Agency for Toxic Substances and Disease Registry (ATSDR, 1995). Results of the assessment showed that fifteen of approximately 180 wells (private wells north and east of the base) had concentrations of contaminants above health guidelines. Concentrations of TCE, PCE, and 1,2-dichloroethane (1,2-DCA) were determined to be of public health concern. Most of the contaminated wells have been removed from service. Several potential sources of groundwater contamination were identified in the ATSDR report, including Tinker AFB; gasoline/petroleum releases from underground storage tank (UST) sites located near the Evergreen Mobile Home Park, and at the intersection of Douglas Boulevard and S.E. 29th Street; a paint shop; a salvage yard; and a vacant lot which contained dumped materials (ATSDR, 1995).

2.2.2 Soldier Creek

The Soldier Creek site includes the main stem of Soldier Creek from its headwaters downstream, its tributaries (East and West Soldier Creeks and tributaries A and B), and any area underlying or adjacent to the waterway that may be contaminated as a result of migration of hazardous substances, pollutants, or contaminants from Tinker AFB (EPA, 1988). These areas are shown on Figure 2.2. West Soldier Creek is the tributary that originates on the west side of Building 3001 and flows northward to its confluence with main Soldier Creek, approximately 2 miles downstream. East Soldier Creek is the tributary which originates just to the north of Building 3705, flows northward along the east side of Building 3001, and joins main Soldier Creek approximately 1 mile downstream.

Previous investigations for the Soldier Creek site are reviewed in the RI report (Parsons ES, 1998). Several investigations relevant to the risk assessment are summarized below. The site was added to the NPL in 1987. In 1990, an RI and risk assessment were performed (B&V, 1993a; 1993b). Exposure to volatile organic compounds, semivolatile organic compounds, and metals in East and West Soldier Creeks sediment and surface water was not found to pose a human health threat.

The ATSDR (1995) public health assessment for the Building 3001/Soldier Creek sites was also reviewed in the RI. In addition to the results of the groundwater assessment (discussed above in Section 2.2.1), ATSDR reported that no chemicals were found above health criteria levels in samples of surface water and sediment from main Soldier Creek, but several contaminants in surface water and/or sediment samples collected from East and West Soldier Creeks were above comparison values (ATSDR, 1995). Typical compounds of concern included bromodichloromethane, TCE, polycyclic aromatic hydrocarbons (PAHs), and inorganics (including arsenic, beryllium, cadmium, chromium, and lead).

In September 1993, a ROD was signed (B&V, 1993c), which mandated a long-term monitoring (LTM) program and an ecological investigation of the sediment and surface water. The LTM program is currently underway. The Ecological Assessment has been completed.

2.2.3 Industrial Wastewater Treatment Plant

The industrial wastewater treatment plant (IWTP) and the sanitary wastewater treatment plant (SWTP) are located within the Tinker AFB Wastewater Treatment Facility (WWTF) on 4 acres at the northeast corner of the base. The SWTP, constructed in 1942 and 1943, treated sanitary wastewater from the east side of the north/south runway, which included the Douglas Aircraft Plant. From 1963 to 1972, the SWTP treated combined industrial and sanitary wastewaters; however, no industrial wastewater has been treated at the SWTP since 1972. The IWTP was constructed in 1972 for treating painting and stripping wastestreams; currently, the major sources of flow are from maintenance processing and electroplating operations which generate wastewater containing oil and grease, metals, and organics (e.g., methylene chloride and phenols). Treated wastewaters from the IWTP and the SWTP were discharged into Soldier Creek under a National Pollutant Discharge Elimination System (NPDES) permit until June 1996 when the base permanently diverted discharge to the Oklahoma City Wastewater Collection System.

Following detection of several contaminants in groundwater near the site, especially certain volatiles not characteristic of Building 3001 (vinyl chloride and chlorobenzene), the IWTP was investigated under several projects. These investigations are reviewed in the RI report (Parsons ES, 1998). Other contaminants found in groundwater in the investigations included 1,1-dichloroethane, DCE, PCE, TCE, 1,2-dichlorobenzene, 1,3-dichloropropane, methylene chloride, 1,1,1-trichloroethane, chromium, and lead. A phase I Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) at the IWTP identified six solid waste management units (SWMUs) from which releases to the environment may have occurred (ES, 1994). The phase II RFI report (Parsons ES, 1996), identified two areas (blending tanks and the industrial sludge drying beds) where surface and subsurface soil contamination may have leached and/or infiltrated to groundwater. However, soil analytical results indicated only localized areas of surface contamination, and only limited further action was recommended.

2.3 HYDROGEOLOGICAL FEATURES

2.3.1 Regional Hydrogeology

At Tinker AFB, three primary geologic units occur at the surface: the Hennessey Shale, the Garber-Wellington Formation, and the Quaternary alluvium. The Hennessey Shale crops out over the southern half of Tinker AFB and consists of reddish-brown shale with beds of siltstone and silty sandstone. It is underlain by the Permian Garber Sandstone and Wellington Formation which, due to their lithologic similarities, are referred to as one unit (the "Garber-Wellington Formation"). This formation is approximately 900 feet thick in the area and consists of lenticular and interbedded sandstone, shale, and siltstone. The Quaternary deposits are found overlying present-day stream valleys and consist of unconsolidated weathered bedrock, fill material, wind-blown sand, and interfingering lenses of sand, silt, clay, and gravel of fluvial origin.

Tinker AFB lies within the limits of the Garber-Wellington Groundwater Basin, which is also referred to as the Central Oklahoma aquifer. This aquifer provides the most significant source of potable groundwater in the Oklahoma City area. Tinker AFB and the nearby communities of Midwest City and Del City derive a portion of their water supply from the Central Oklahoma aquifer. The aquifer has been grouped as a Class IIA aquifer by the State of Oklahoma (OAC 785: 45-7, Appendix A), indicating that it provides groundwater from a major unconfined basin which is capable of being used as a drinking water supply with little or no treatment.

Recharge of the Central Oklahoma aquifer is accomplished principally by rainfall infiltration and percolation of surface waters crossing outcrop areas. Most of Tinker AFB is situated in an aquifer outcrop area and, as such, is situated in a recharge zone. The quality of groundwater derived from the aquifer is generally good, although wide variation in the concentrations of some constituents (heavy metals, common anions, common cations, and radionuclides) are known to occur. The base water supply wells were screened from approximately 200 feet to 750 feet below ground level (BGL).

2.3.2 Northeast Quadrant Hydrogeology

The Hennessey Shale is absent over most of the conceptual model area and was not encountered in the investigations of the RI. The stratigraphy of the Garber-Wellington Formation, specifically the lower saturated zone (LSZ), is discussed in more detail below. Further information is provided in the RI report (Parsons ES, 1998) and the Groundwater Flow and Solute Transport Modeling interim status report (Battelle, 1995).

The Central Oklahoma aquifer in the northeast quadrant is divided into three major hydrostratigraphic units (HSUs) separated by two distinct shale units. The units have been identified in the area based on stratigraphic correlations of shale beds within the Garber-Wellington and on observed differences in hydraulic head between the primary water-bearing zones separated by shales (Battelle, 1995; Parsons ES, 1998). The three zones are the upper saturated zone (USZ), the lower saturated zone (LSZ), and the production zone (PZ). Depth to water ranges from 15 to 30 feet in the USZ, 50 to 80 feet in the LSZ, and 200 to 250 feet in the PZ. Previous investigations at Tinker AFB have used different terminology to describe the regional hydrostratigraphy. The USZ was previously designated as the "perched" aquifer; and the LSZ corresponds to the aquifers previously referred to as the "top of regional aquifer" and the "regional aquifer."

The USZ portion of the formation is the saturated zone above the upper shale and, at the scale of the northeast quadrant, ranges in thickness from 0 feet (north and east of Building 3001 in an area where the upper shale has been removed by erosion) to 67.6 feet (along the southwest boundary of the Soldier Creek site). The LSZ consists of the saturated interval between the upper and lower shale units. The sediments that comprise the LSZ vary in thickness from approximately 88 to 179 feet, with an average thickness of about 151 feet. In areas where the upper shale unit occurs, the entire column of LSZ sediments is present and generally ranges in thickness from 130 to 170 feet. Beyond the extent of the upper shale, much of the LSZ sediment has been removed by erosion which has reduced the thickness of the sediments, especially along stream drainages. The PZ is the saturated zone beneath the lower shale, ranging in thickness from 725 to 792 feet. The base of the PZ is defined by the base of fresh groundwater.

The LSZ in the northeast quadrant is further divided into four predominantly sandy aquifer zones separated by three intervening shaley horizons (Battelle, 1995). The four aquifer zones are designated as layers 3, 5, 7, and 9. The shaley horizons are designated as layers 4, 6, and 8. Due to the interfingering and discontinuous nature of the shale layers, each layer consists of numerous shale lenses, and each serves as a leaky confining unit for the adjacent aquifer zones.

Water table/potentiometric surface maps for each aquifer zone within the conceptual model area were developed using monthly water level data collected during March 1994 through June 1995 (Battelle, 1995). The maps were used to determine the potential for groundwater flow and contaminant migration pathways from on-base sources. Results of the groundwater flow and migration pathway evaluation (exposure pathways) are presented in the following sections.

2.4 CONCEPTUAL HYDROLOGIC MODEL

The conceptual hydrologic model was used to guide the selection of data to be included in the baseline human health and environmental risk assessment. The conceptual model was developed through the integration of data collected in support of the RI (Parsons ES, 1998) and the Building 3001 groundwater flow and solute transport modeling activities (Battelle, 1995). The groundwater flow modeling report provides a detailed discussion of the conceptual model for the northeast quadrant of Tinker AFB and for adjacent off-base areas.

The conceptual model area is shown in Figure 2.2. The area encompasses property that lies within the boundary of Tinker AFB and off-base property that lies north of the base along Douglas Boulevard. The rationale for delineating the conceptual model area were as follows: (1) the reaches of Soldier Creek within the conceptual model area were the most likely to interact with groundwater associated with the Operable Units; (2) the conceptual model area would account for the region surrounding the focus study area for purposes of geologic and hydrologic extrapolations; and (3) if contamination was found, the source of the contamination could be evaluated in terms of whether Building 3001, Soldier Creek, the IWTP, or off-base source(s) were responsible.

During the IWTP/SCOBGW OUs RI, groundwater samples were collected from 164 wells on and off base in the conceptual model area. These wells included 152 base-owned monitoring wells and 12 privately-owned domestic wells. The base-owned wells included 131 existing wells installed during previous investigations and 21 new wells installed during the RI (Parsons ES, 1998). The well locations for the RI/FS are shown in Figure 2.3.

Monitoring wells were typically grouped into clusters of three wells with screening intervals set at depths of approximately 50, 100, and 150 feet BGL. Typically, within the areal extent of the USZ, new well clusters had one screen set in the USZ and two screens set in the LSZ. New well clusters installed outside the areal extent of the USZ had screens set at three different levels within the LSZ. Several well clusters consisted of four wells, with the fourth well screened in either the LSZ or the PZ. The well-numbering system included the well cluster location number (e.g., Tinker off-base well 6, TOB-6), followed by references to the various screening depths for each well in the cluster (e.g., TOB-6A, B, C).

2.5 GROUNDWATER FLOW AND MIGRATION PATHWAY ANALYSIS

2.5.1 Upper Saturated Zone Flow

The USZ is a shallow water table aquifer which occurs primarily within the boundaries of Tinker AFB, but extends across the northeastern boundary into the Kimsey Addition and north to Interstate 40 within the conceptual model area. The Kimsey Addition is located north of Building 3001 and the IWTP, and consists of approximately one hundred private residences. Residences located within a portion of the Kimsey Addition were purchased by Tinker AFB in 1990 are no longer in existence. They were demolished and replaced with Tinker buildings. The extent of the USZ is shown in Figure 2.4.

Within the USZ, a groundwater mound occurs between Building 3001 and the Kimsey Addition. Radial flow emanates in several directions from the mound. For most areas, USZ groundwater flows to the west-southwest. East of Building 3001, groundwater flows to the east towards the margin of the USZ.

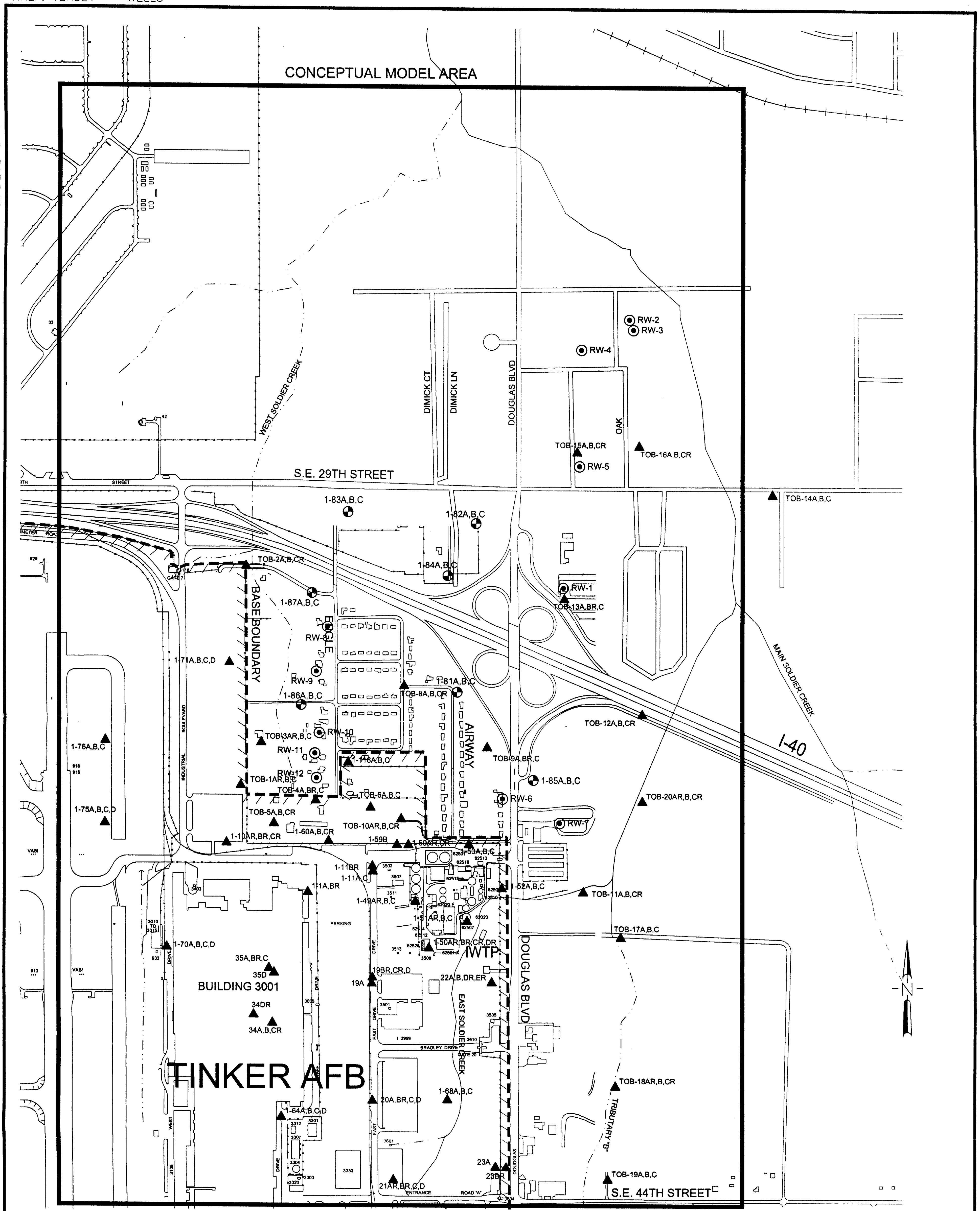
2.5.2 Lower Saturated Zone Flow

Within the conceptual model area, the LSZ thins to the north and east going updip towards Soldier Creek. The most prominent features of the LSZ (layers 3, 5, 7, and 9) are groundwater flow divides that generally trend northwest-southeast and appear to be associated with the margin of the USZ. The locations of the groundwater flow divides for layers 3, 5, 7, and 9 are shown in Figures 2.5, 2.6, 2.7, and 2.8, respectively. These locations were based on data collected in June 1995. The locations of all of the divides are shown in Figure 2.9.

The IWTP area occurs primarily within the outcrop of the LSZ. The divide in layer 3 (see Figure 2.5) closely follows the USZ margin until reaching the IWTP area. This suggests the USZ margin west of the IWTP area is more permeable and is allowing the movement of more USZ groundwater down to the LSZ than the eastern margin of the USZ. With increasing depth in the LSZ, the locations of the divides shift north or south, but remain fairly constant within a given layer.

XREF: TBASE1 WELLS

721447-11040 WELLS-RAF.DWG



LEGEND

1-85 NEW MONITORING WELL CLUSTER LOCATION AND NUMBER

nnn R EXISTING MONITORING WELL CLUSTER LOCATION AND NUMBER
R = REPLACEMENT WELL

RW5 RESIDENTIAL WELL LOCATION AND NUMBER

INTERMITTENT STREAM

PERENNIAL STREAM

BASE BOUNDARY

750 0 750
SCALE FEET

Figure 2.3
Location of
Groundwater Monitoring Wells
for IWTP/SCOBGW OUs RI

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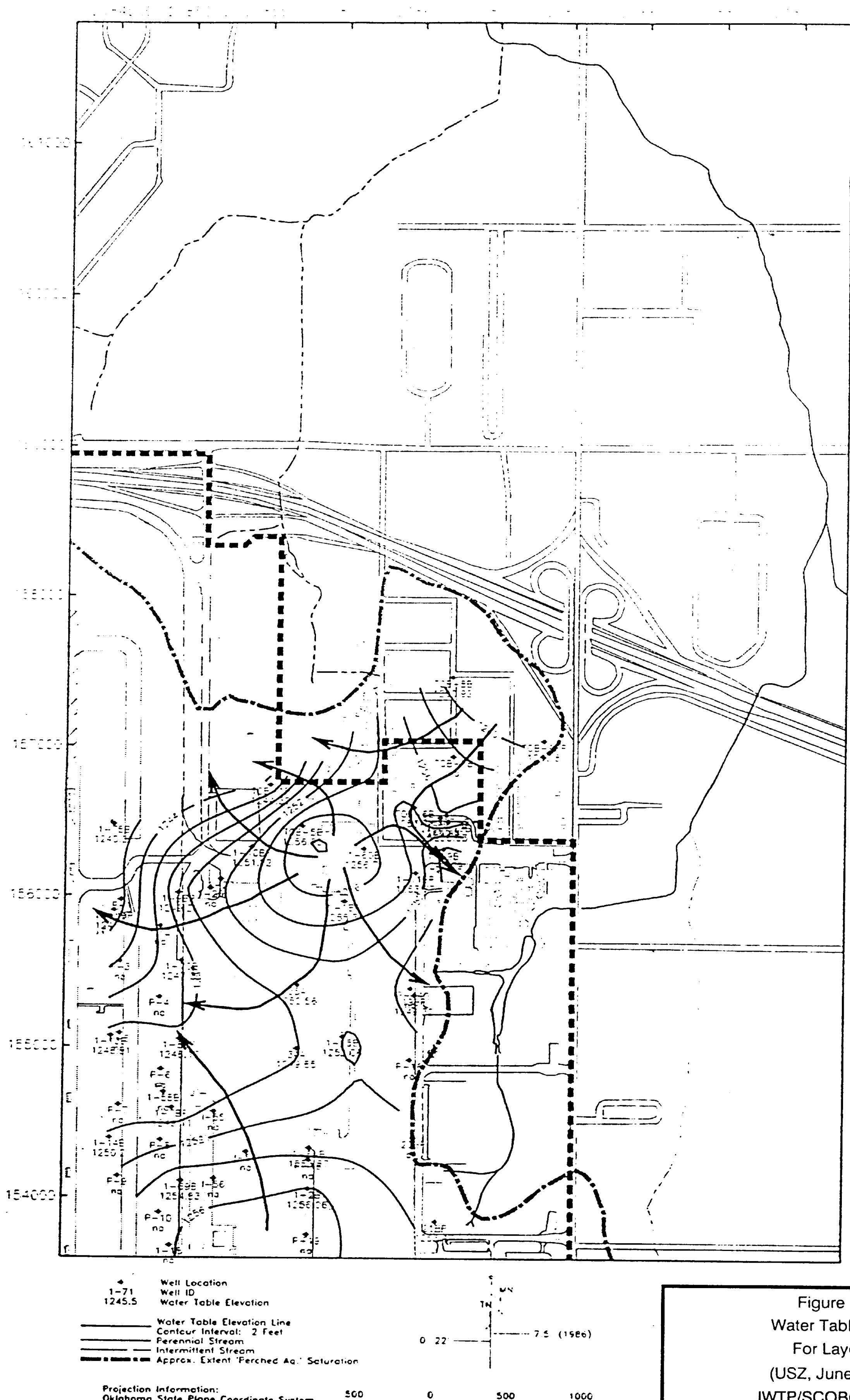

Figure 2.4
Water Table Map
For Layer 1
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

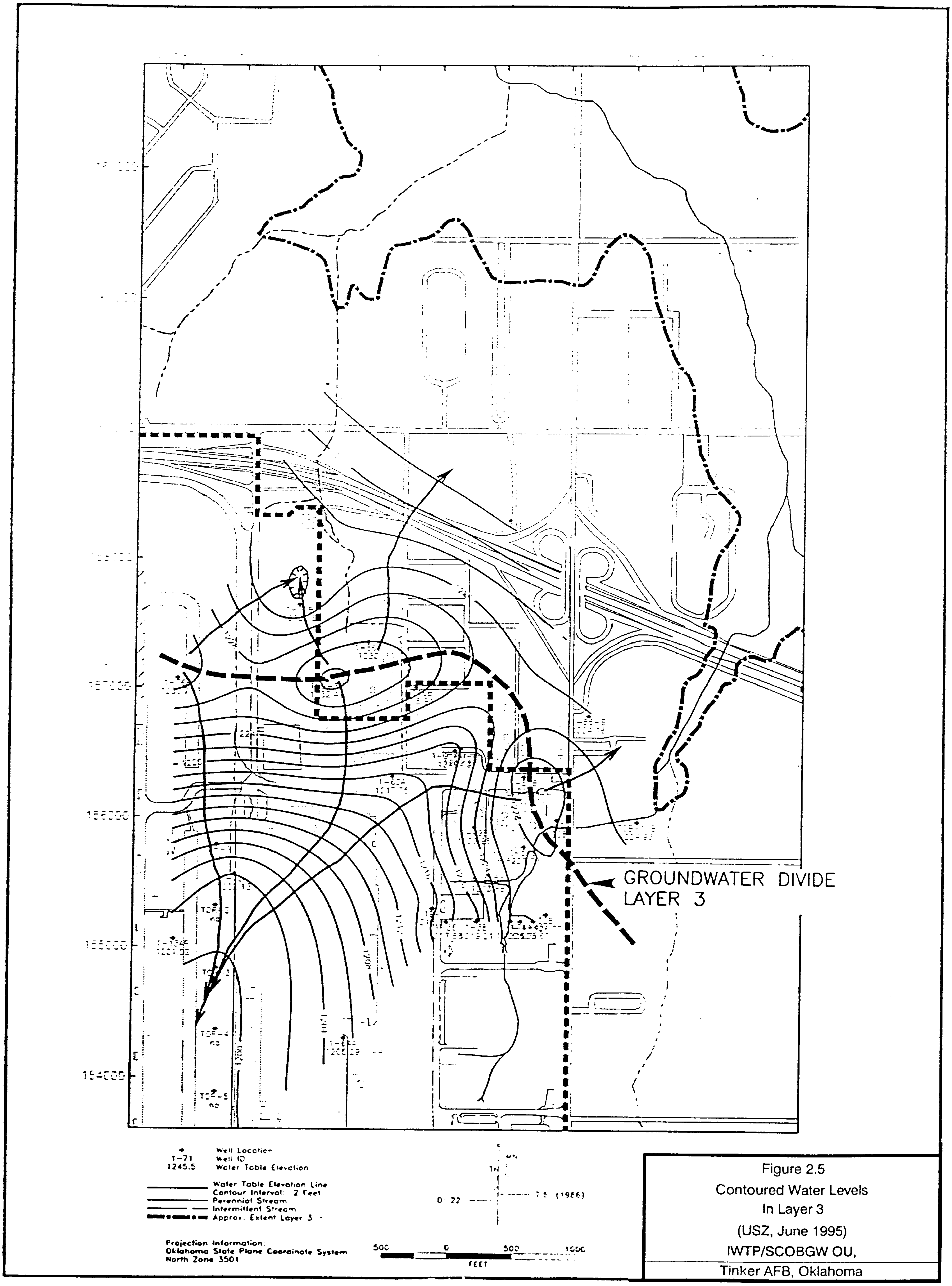

Figure 2.5
Contoured Water Levels
In Layer 3
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

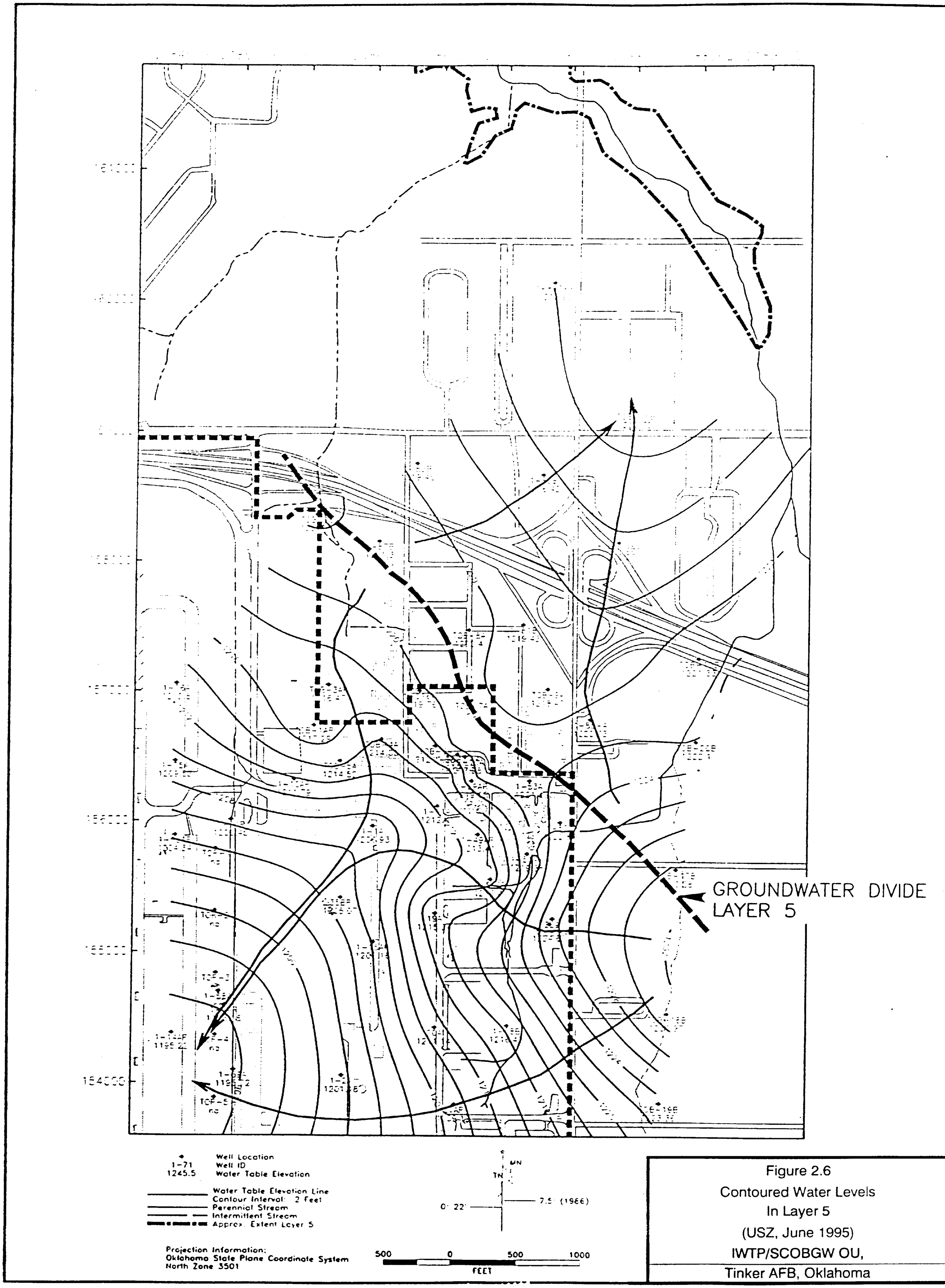

Figure 2.6
Contoured Water Levels
In Layer 5
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

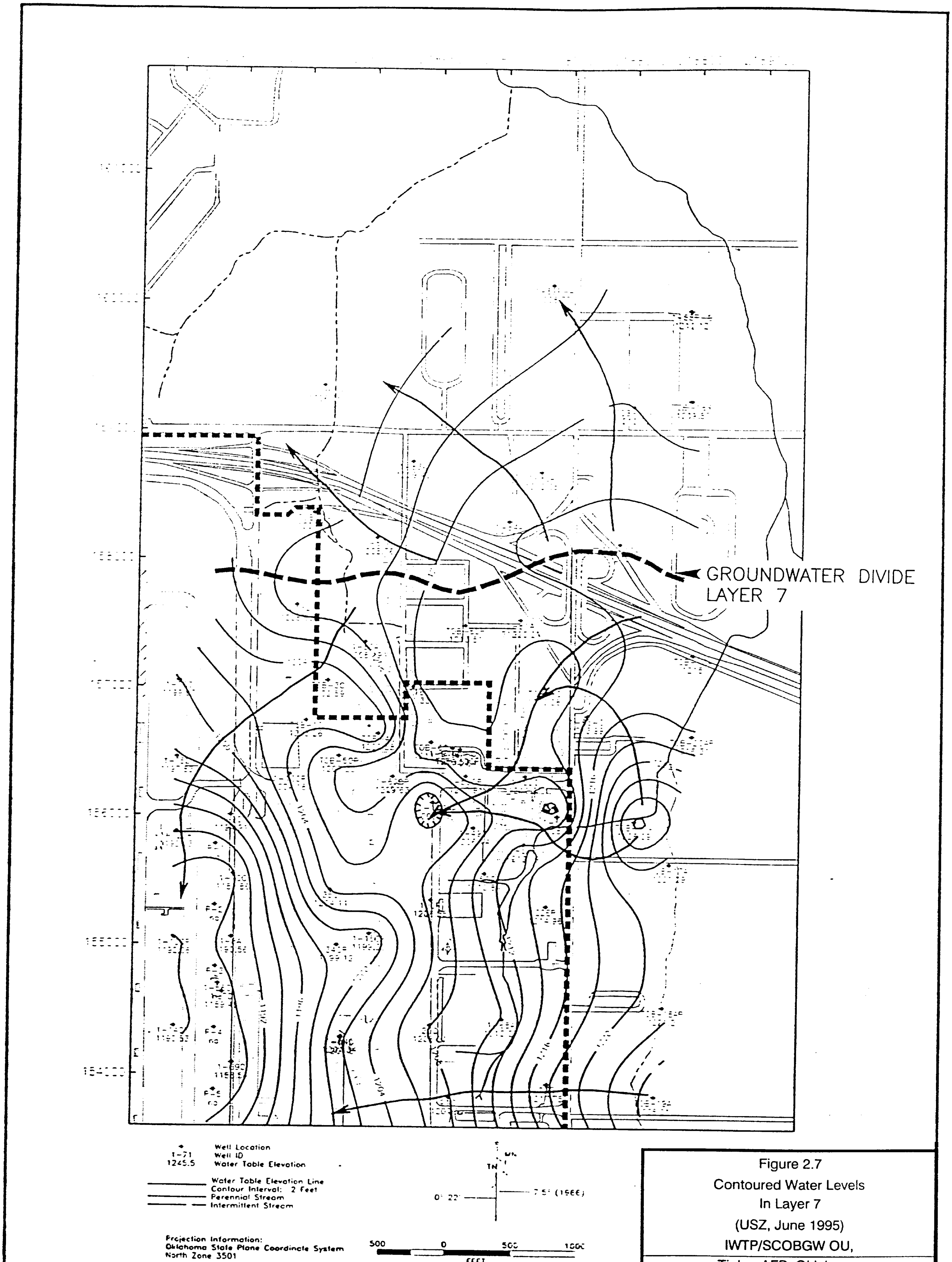

Figure 2.7
Contoured Water Levels
In Layer 7
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

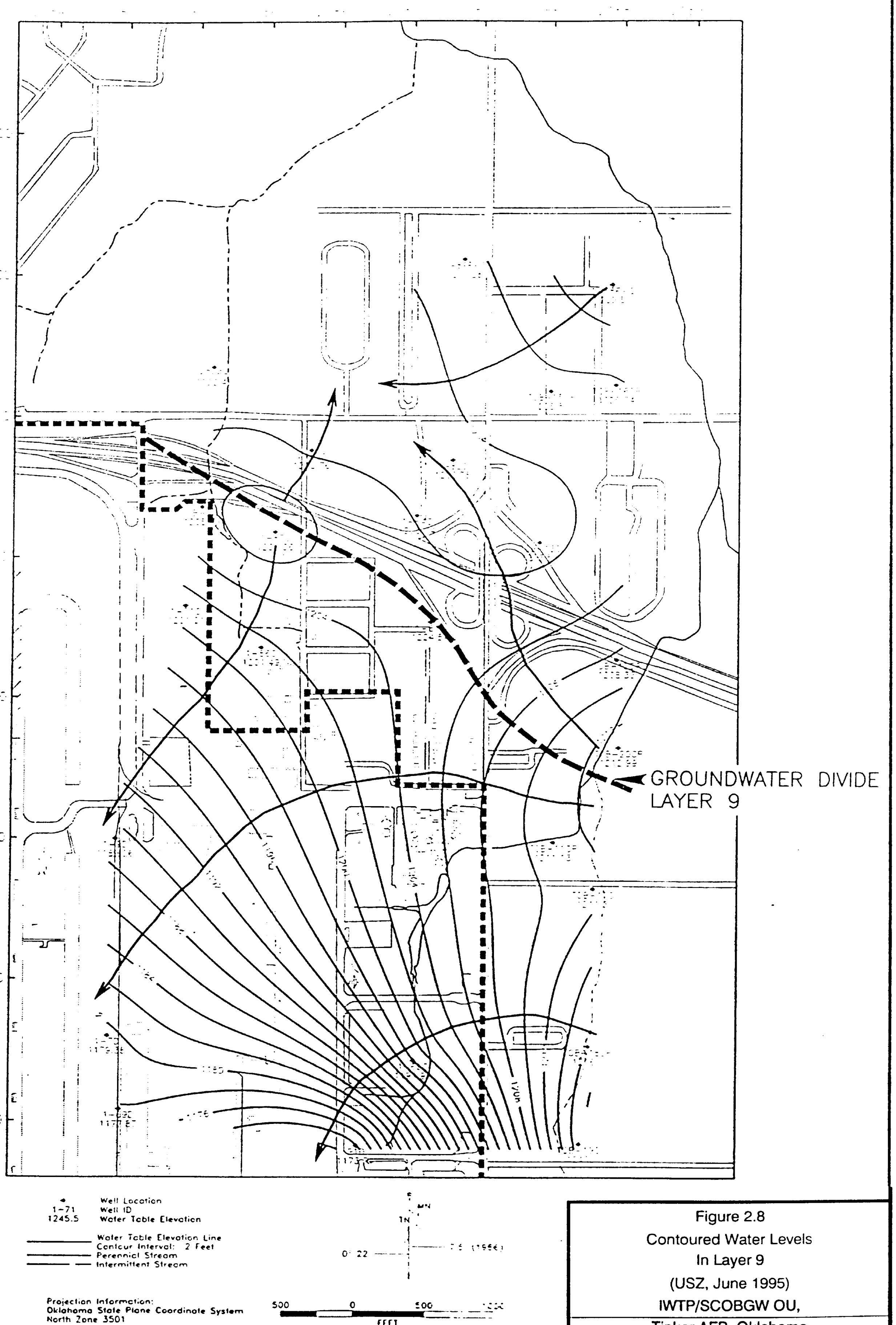

Figure 2.8
Contoured Water Levels
In Layer 9
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

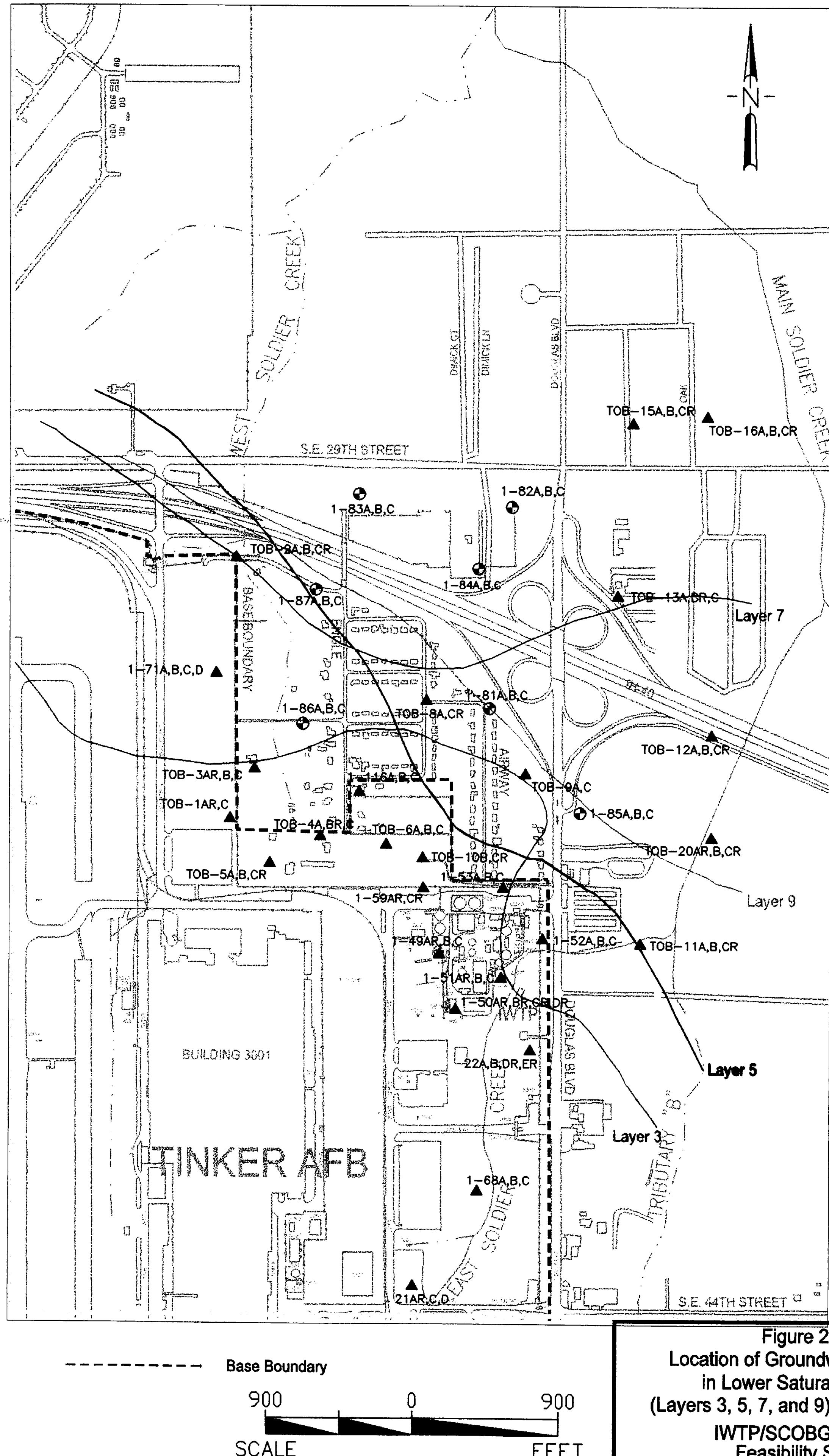

Figure 2.9
Location of Groundwater Divides
in Lower Saturated Zone
(Layers 3, 5, 7, and 9) February 1995

IWTP/SCOBGW OUs
Feasibility Study
Tinker AFB, Oklahoma

721447-11040 LSZ3579F.DWG

Within each LSZ layer the location of the divide determines the potential migration pathways (i.e., within each layer, contamination beneath Building 3001 has limited potential to migrate to the north or east via the groundwater pathway). In general, groundwater south of the divides flows to the south-southwest; groundwater north of the divides flows to the north.

Although the locations of the LSZ groundwater divides indicate that some movement of groundwater off base to the north via a "stair-step" phenomenon is possible, analytical data from wells on base and off base indicate that it is unlikely this occurred. A large TCE plume and several small plumes of chlorinated solvents and metals have been identified south of the groundwater divides. Only spotty hits of contamination have been identified north of the groundwater divides.

2.5.3 Production Zone Flow

The groundwater flow direction within the production zone (layer 11) is variable at the base, but is primarily to the south-southwest in response to pumping at base water supply wells. Layer 11 contoured water levels are shown in Figure 2.10. However, there are no water supply wells which influence PZ flow in the northeast corner of the base, and flow is primarily to the south. More detailed descriptions of flow within this zone are provided in the RI (Parsons ES, 1998) and Battelle (1995) reports.

2.6 SUMMARY OF REMEDIAL INVESTIGATION

The following is a brief summary of the remedial investigation (RI). More complete information on the methods and results of the investigation can be found in the RI report (Parsons ES, 1998).

Field work was conducted from May 1994 through August 1995. Geophysical logging, downhole video inspections, and groundwater sampling were performed on twelve private wells. Four 200-foot soil and rock cores were obtained in four different locations of the conceptual model area. Twenty-one monitoring wells and twelve piezometers were installed. A total of 152 monitoring wells were sampled. Two stream gaging stations, six streambed piezometers, and eight staff gages were installed. Between July 1994 and August 1995, monthly measurements were obtained at the six existing and the two newly-installed stream gaging stations along with the six streambed piezometers and eight staff gages. Bi-monthly measurements were made in 176 wells between December 1994 and June 1995. Thirty-three additional wells were gaged in December 1994 and April 1995. One aquifer pumping test was performed in the USZ and two in the LSZ. Four soil samples were collected from one location and forty-five sediment

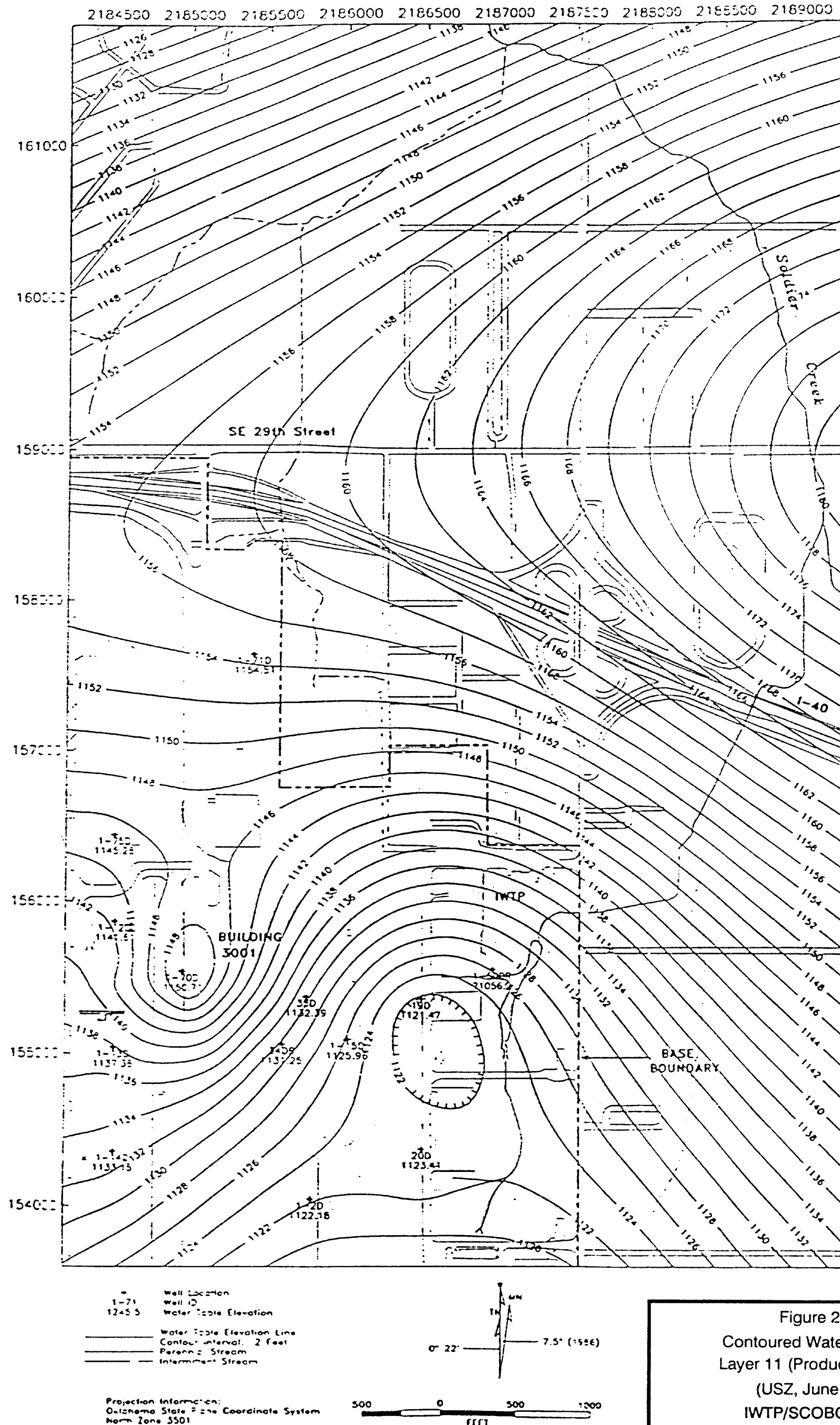

Figure 2.10
Contoured Water Levels in
Layer 11 (Production Zone)
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

samples were collected from nine locations. Field sampling data were incorporated into the conceptual model to establish the current understanding of groundwater occurrence and migration.

The geological and geophysical data collected from the private wells, coreholes, and monitoring wells were incorporated into the conceptual model to define the subsurface stratigraphy. The data from the stream investigations, well measurements, and aquifer pumping tests were then used to define the hydrostratigraphic layers within the conceptual model area. Data collected during the RI augmented the eleven-layer conceptual model described in Section 2.5.2. As described above, the six water-bearing units consist of one layer (layer 1) in the USZ, four layers in the LSZ (layers 3, 5, 7, and 9), and one layer (layer 11) in the PZ. Groundwater elevation contour maps depict a major groundwater divide in all LSZ layers in a location generally between the northeastern portion of the base and Interstate 40.

Results of the aquifer pumping tests confirm the presence of vertical gradients across the study area; however, the LSZ appears to be hydraulically separated from the overlying USZ and the underlying PZ by confining shales. Prolonged pumping of the USZ was not possible due to low aquifer yield and a limited saturated thickness; however, step drawdown results and recovery analyses indicate a hydraulic conductivity of 2.3 ft/day (8.1×10^{-4} cm/sec) in the USZ. Water level monitoring during pumping of the LSZ wells indicated that layers of the LSZ are vertically connected. The average hydraulic conductivity value for the upper LSZ is 5.17 ft/day (1.8×10^{-3} cm/sec), with an average aquifer storativity of 0.03, an average leakance coefficient of 0.11, and a calculated vertical hydraulic conductivity of 1.16 ft/day (4.1×10^{-4} cm/sec) in the aquitard. The average hydraulic conductivity for the lower LSZ is 6.08 ft/day (2×10^{-3} cm/sec), with an average aquifer storativity of 1.7E-04, an average leakance coefficient of 0.48, and an average vertical hydraulic conductivity of 8.7E-03 ft/day in the aquitard. Effects of the Building 3001 groundwater recovery/remediation system were quite noticeable, particularly during the lower LSZ pumping test. No pumping tests were performed in the PZ to discern if there is vertical communication across the shale confining bed separating the LSZ and the PZ. However, available information indicate that it appears that the PZ is not in direct communication with the overlying LSZ, at least in the Building 3001 and IWTP/Soldier Creek area. The confining shale layer separating the LSZ and the PZ is over 20 feet thick. The head difference between the wells installed in the LSZ and PZ is over 70 feet, indicating that the shale layer is a good confining bed with low permeability.

the benzene contamination associated with the private well are likely due to the local UST source.

The IWTP/SCOBGW OUs RI (Parsons ES, 1998) presented the plume maps for TCE, PCE, 1,2-DEC, VC, chromium, and nickel. Comparatively, TCE plumes were the largest among all the contaminants in all the layers. Thus, TCE plumes are used as an indicator and are reproduced as Figures 2.11 to 2.14 which correspond to layer 1 through layer 7. There were no contaminants exceeding MCLs in layer 9 monitoring wells, and there were no plumes. For the PZ, i.e., layer 11, the TCE plume exceeding MCL of 5 μg/L is located to the west side of Building 3001; there is no plume underneath the IWTP/SCOBGW OUs focused area, and the plume map is not reproduced here. In reference to Figure 2.2 which shows the focused study area, Figures 2.11 to 2.14 indicate that the plumes of Building 3001 and of the IWTP/SCOBGW OUs are mingled and coalesced.

In addition to the groundwater contamination migration pathway, the surface water to groundwater pathway was evaluated. The potential for infiltration of surface water to groundwater was evaluated in three ways: (1) the evaluation of groundwater elevation contours, (2) the calculation of stream discharge based on stream stage measurements, and (3) the evaluation of streambed permeability. Groundwater elevation contours indicate that Soldier Creek is potentially losing water on base.

Streambed permeability data indicate that streambed sediments consist primarily of low permeability shales which are unlikely to allow significant amounts of flow. However, discharge data indicate that most segments of Soldier Creek lose water to evapotranspiration in summer.

Contamination levels and types in creek sediment and groundwater neighboring wells were compared to further evaluate the possibility that past releases of contaminants to the creek could have contaminated groundwater. High levels of chlorobenzene and jet fuel components were found in sediment samples near the IWTP outfall which is located along one of the aquifer recharge zones in East Soldier Creek. Low levels of TCE and PCE have been detected in the groundwater in off-base wells located adjacent to the creek. It should be noted that the contaminants found in these wells did not match the contaminants found in sediment. Although previous on-base sediment removal actions have reduced much of the source in this area, a potential existed for the past migration of contaminants from Soldier Creek to the LSZ due to leaching. PAH contamination has

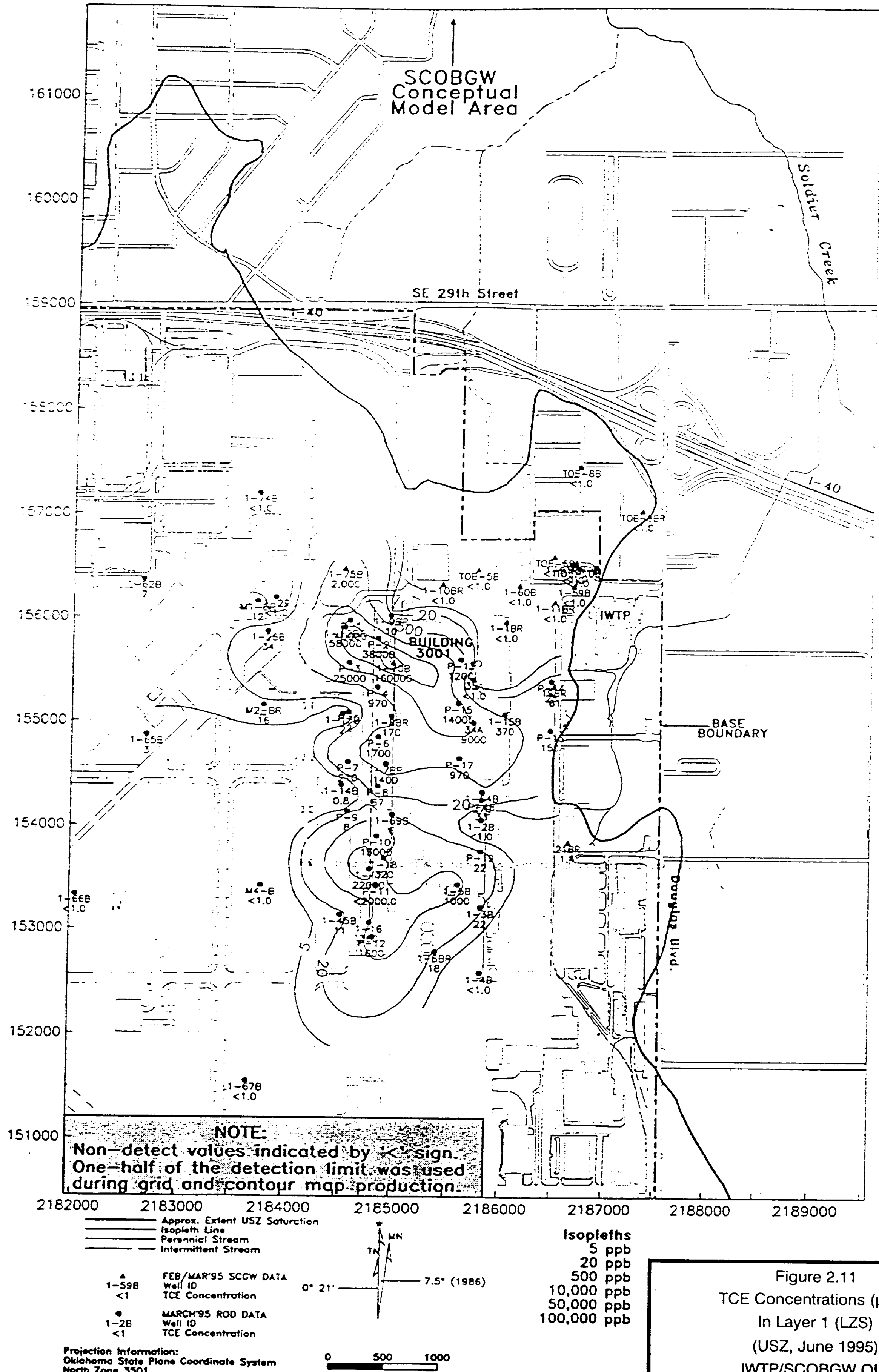

Figure 2.11
TCE Concentrations (µg/L)
In Layer 1 (LZS)
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

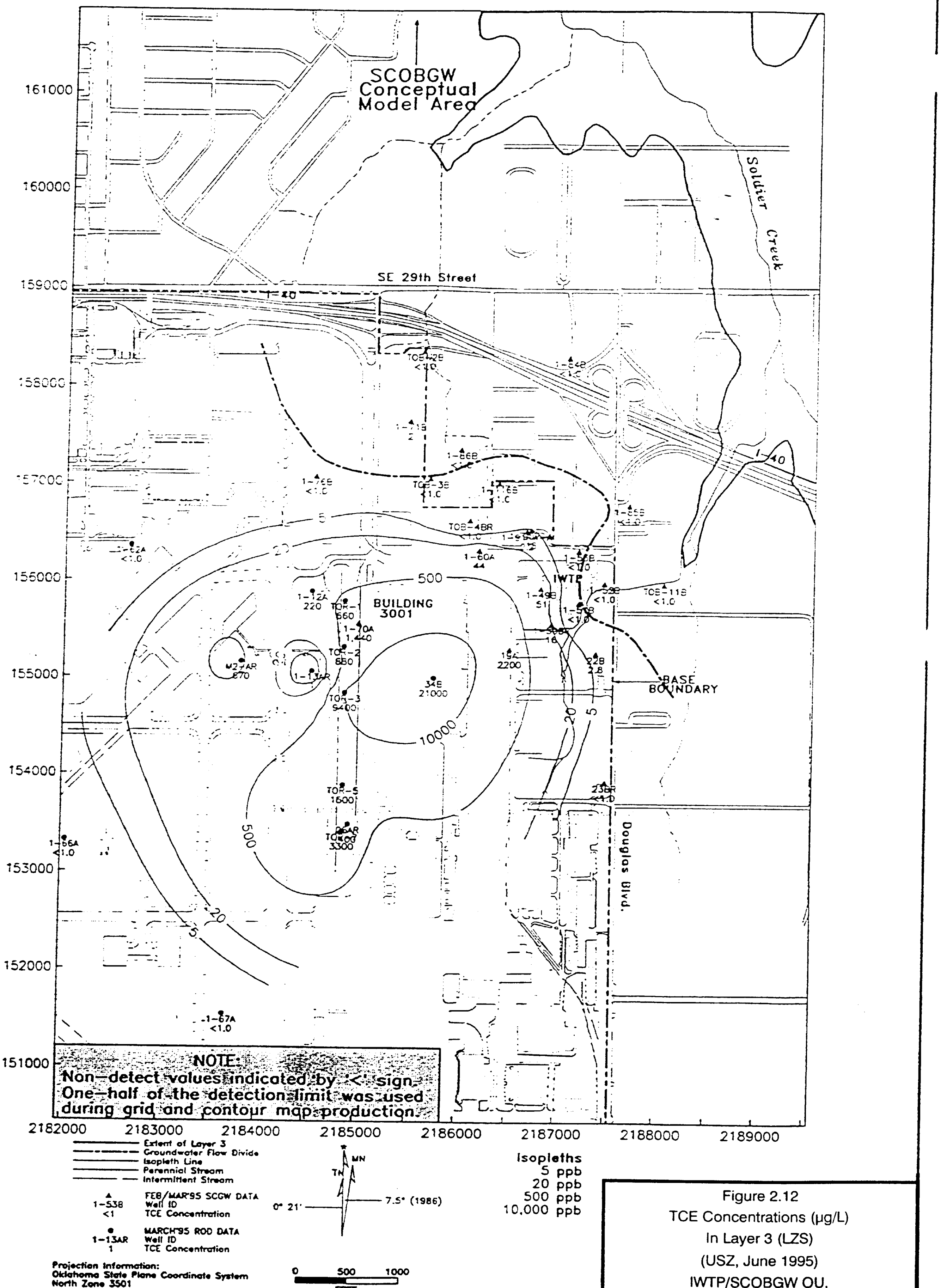

Figure 2.12
TCE Concentrations (µg/L)
In Layer 3 (LZS)
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

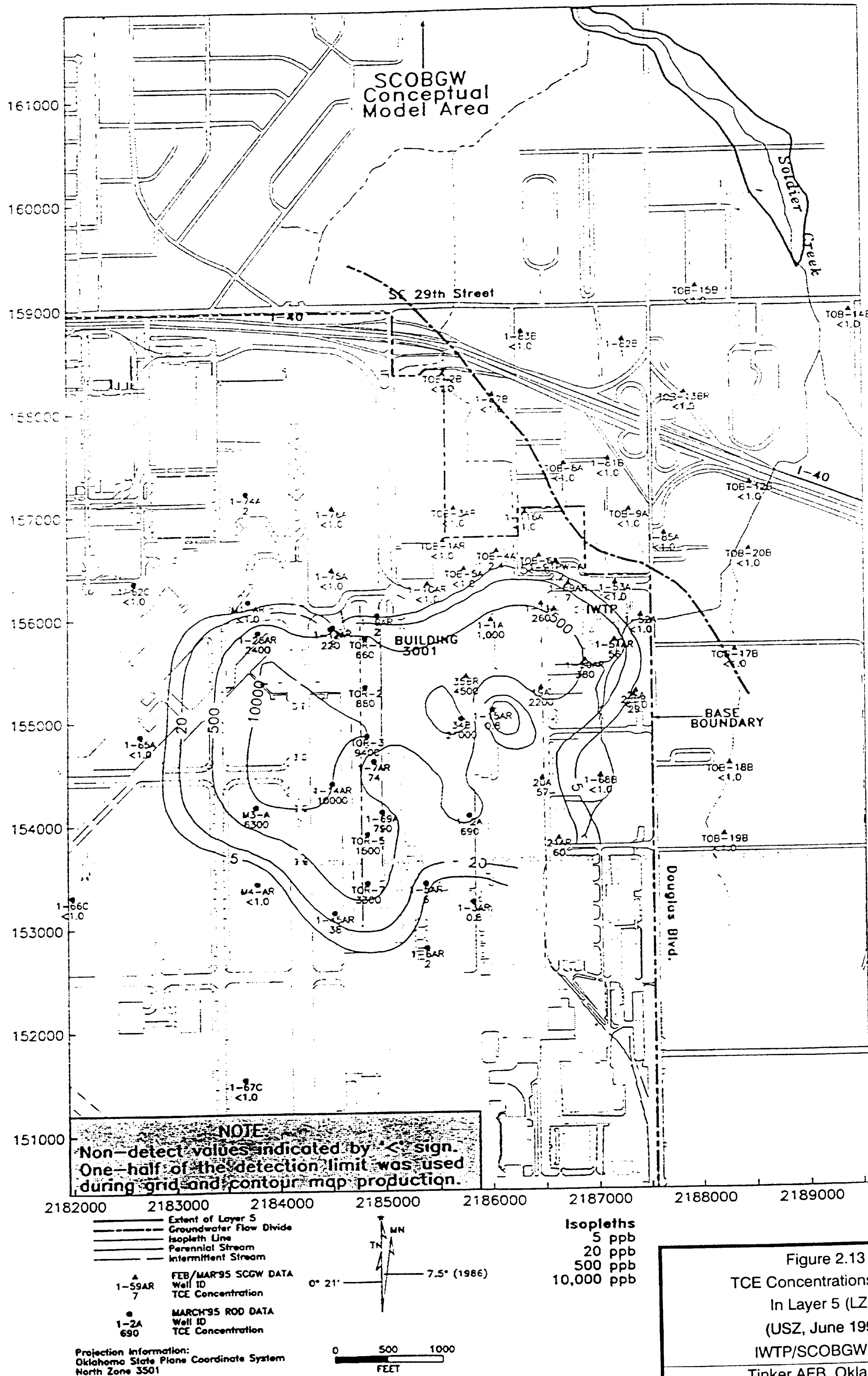

Figure 2.13
TCE Concentrations (µg/L)
In Layer 5 (LZS)
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

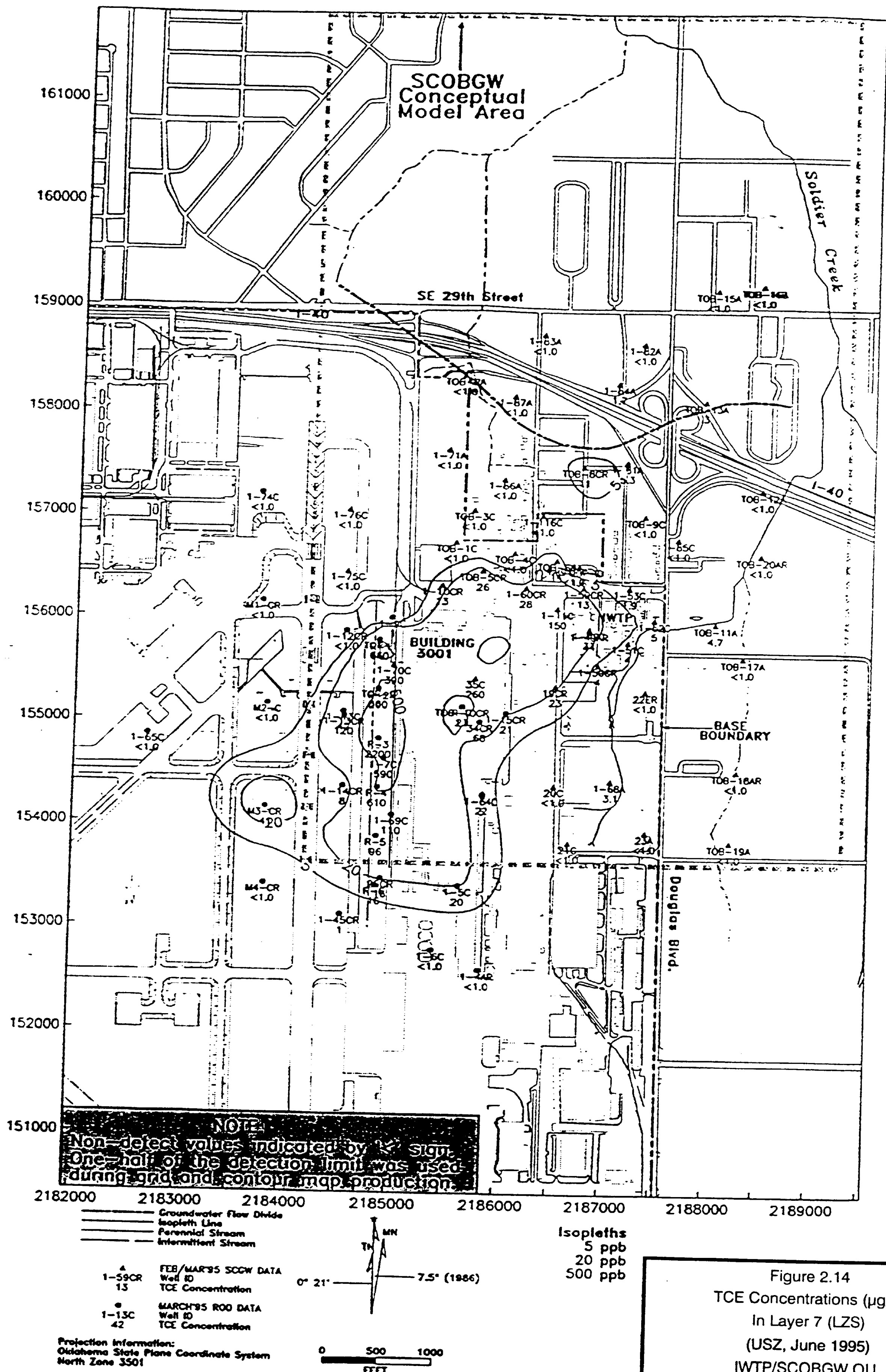

Figure 2.14
TCE Concentrations (µg/L)
In Layer 7 (LZS)
(USZ, June 1995)
IWTP/SCOBGW OU,
Tinker AFB, Oklahoma

been documented in sediment samples collected north of I-40 along West Soldier Creek but not upstream from I-40 near the base's spill control sluice. There is no definite plume extending north and east of the base along the creeks, but only spotty, low levels (generally below MCLs) of contamination were detected in off-base areas.

2.7 SUMMARY OF RISK ASSESSMENT

2.7.1 Selection of Wells and Sampling Data

The groundwater monitoring wells for the baseline human health and environmental risk assessment were selected based on the three major aquifer zones (USZ, LSZ, and PZ) and the location of the LSZ groundwater flow divides. Based on these features, five well groups within the conceptual model area were designated for risk assessment. These well groups are referred to as conceptual model well groups and are shown in Figure 2.15.

The locations of the groundwater divides within the LSZ were evaluated using monthly water level measurements collected during February 1995. Use of water level measurements taken during the February time frame is appropriate because this was the same time frame in which the monitoring wells were sampled. (Monitoring wells selected for the risk assessment were sampled in February and March 1995.) The divides for each LSZ layer were overlain to determine the southernmost extent of the divides. For purposes of the risk assessment, the southern extent of the divides is referred to as the "groundwater flow boundary," representing the predominant boundary of LSZ flow back towards the base. The location of the groundwater flow boundary is also shown in Figure 2.15.

Monitoring wells north of the groundwater flow boundary were selected for inclusion in the risk assessment because of the potential migration pathways discussed above (potential "stair-step" effect due to lateral movement of groundwater within layers and vertical movement across layers). One conceptual model well group was designated for LSZ groundwater north of the groundwater flow boundary.

Monitoring wells south of the groundwater flow boundary were selected for inclusion in the risk assessment because of the potential for movement of contaminants from Building 3001 or the IWTP; potential influence by water loss from Soldier Creek; and potential leakage of USZ groundwater along the USZ margin. For LSZ and USZ groundwaters south of the groundwater flow boundary, three conceptual model well groups were designated. Monitoring wells located in the former Kimsey Addition were grouped separately from monitoring wells located east of East Drive, and USZ and LSZ groundwater in each of these areas were also grouped separately.

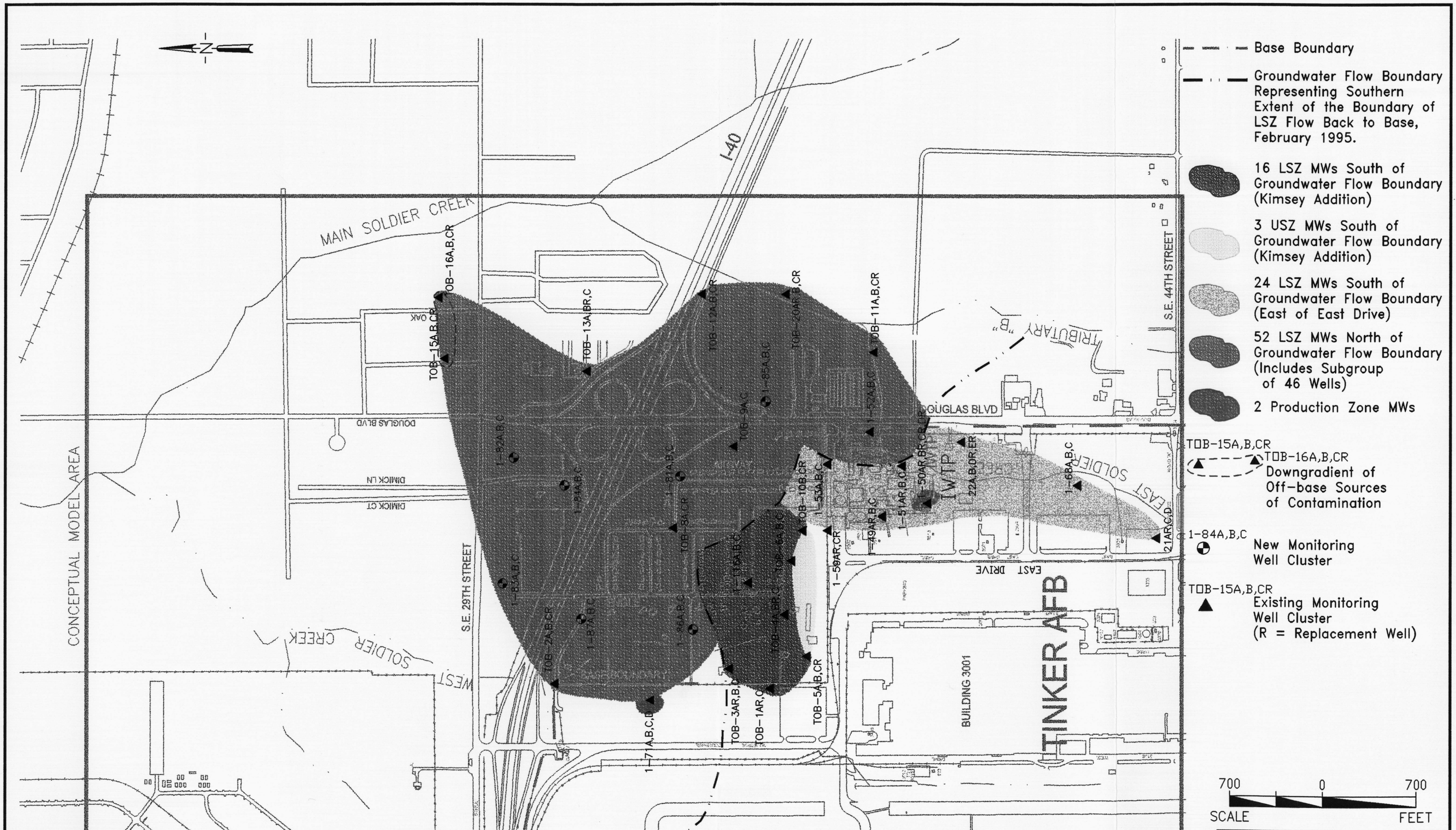

Figure 2.15
Location of
Groundwater Monitoring Wells and
Conceptual Model Well Groups for
Feasibility Study

Tinker AFB, Oklahoma

721447-11040 Risk2F.dwg

One conceptual model well group was also designated for the PZ monitoring wells. These wells were included in the risk assessment due to the potential for contaminants to leak through discontinuous shale layers.

Based on the hydrological interpretation for designation of the five conceptual model well groups, chemistry data from a total of ninety-seven wells were carried through the baseline risk assessment. Table 2.1 lists the individual wells within each well group and the rationale for well group selection. Rationale for wells not selected for risk assessment are also given. In summary, the five well groups include:

1) Sixteen LSZ monitoring wells south of groundwater flow boundary (within the former Kimsey Addition). Area of LSZ is upgradient from Building 3001; represents an area where potential contamination may have resulted from the leakage of USZ water (along margin) into the LSZ.

2) Three USZ monitoring wells south of groundwater flow boundary (within the former Kimsey Addition). Well TOB-5B is downgradient from Building 3001, while TOB-6B and TOB-10B are upgradient (see Figure 2.4); TOB-5B represents a possible area for leakage of USZ water (along margin) into the LSZ.

3) Twenty-four LSZ monitoring wells south of groundwater flow boundary (east of East Drive). Area may be potentially influenced by water loss from Soldier Creek, and/or flow from the IWTP area.

4a) Fifty-two LSZ monitoring wells north of groundwater flow boundary. Location of layer 3 divide in the IWTP area resulting in groundwater flow to the north, and possible infiltration of surface water to groundwater from influent areas of Soldier Creek.

4b) Subgroup of forty-six LSZ monitoring wells north of groundwater flow boundary. Wells were evaluated as a subgroup based on evidence of off-base sources of contamination near and upgradient of two well clusters (six wells).

5) Two PZ monitoring wells representing base water supply. Wells may be potentially contaminated due to leakage of contaminants through discontinuous shale layers, and/or a possible fracture component of groundwater flow.

2.8 SUMMARY OF HUMAN HEALTH RISK ASSESSMENT RESULTS

The human health risk assessment is completed (Parsons ES, 2000); results are available and are described in this section. For each conceptual model well group, carcinogenic and noncarcinogenic risks were estimated for each of the chemicals of potential concern and potential exposure pathways (ingestion of chemicals in groundwater used as drinking water, dermal contact with contaminants in groundwater while showering, inhalation of volatiles from groundwater while showering, and ingestion of contaminants in homegrown fruits and vegetables following irrigation with groundwater).

The overall results of the human health risk assessment showed reasonable maximum exposure (RME) estimates of cancer and/or noncancer risk exceeding acceptable EPA health protective thresholds (1.0E-04 and 1.0, respectively) in three of the five conceptual model well groups. The well groups with the exceedances were the three LSZ well groups:

- The sixteen LSZ wells in the former Kimsey Addition;
- The twenty-four LSZ wells east of East Drive;
- The group of fifty-two LSZ wells north of the groundwater flow boundary; and
- The subgroup of forty-six wells north of the groundwater flow boundary.

For the USZ wells (three wells in the former Kimsey Addition) and the PZ wells, RME risk estimates fell below both the lower bound of the acceptable risk range (1.0E-06) and the noncarcinogenic health-protective threshold (1.0).

2.8.1 Contaminants of Concern

Tables 2.2 through 2.5 present the chemistry data for each of the conceptual model well groups. The complete analytical results from the remedial investigation are in the RI report (Parsons ES, 1998). The qualitative comparison criteria included local base and regional background levels (Parsons ES, 2000; ODEQ, 1995; USGS, 1993), and numerical water quality levels, including maximum contaminant levels (MCLs) (EPA, 1995b) and Oklahoma drinking water regulations and groundwater quality standards (BNA, 1994). MCLs are enforceable standards which apply to public drinking water systems. These standards are based on allowable lifetime exposure in drinking water for an adult, but also reflect the technical and economic feasibility of removing the contaminant from the water supply. Similar to the federal MCLs, the Oklahoma State drinking water regulations are enforceable standards which apply to public water systems. The state groundwater quality standards are used to identify contaminated groundwater, but are not considered to be enforceable by the state.

Figure 2.16 shows the locations of the wells where concentrations of contaminants were estimated to contribute most to the unacceptable cancer risk or noncancer hazard index (HI). Only the wells with elevated levels of contaminants that contributed most to

Table 2.1. Rationale for Selection of Wells and Conceptual Model Well Groups for Risk Assessment.

Conceptual Model Well Group	Well Numbers	Well Location Relative to Base Boundary	Wells Retained or Excluded in Baseline Risk Assessment*	Rationale for Well Selection
16 LSZ Monitoring Wells, South of Groundwater Flow Boundary, Kimsey Addition (wells represent layers 3, 5, 7, and 9)	1-116 A, B, C TOB-1 AR, C TOB-3 AR, B, C TOB-4 A, BR, C TOB-5 A, CR TOB-6 A, C TOB-10 CR	On base On base Off base On base On base On base On base	Yes	• Wells are located within residential area at northeastern base boundary (north of industrial area of the base). • Potential for current and future use of water as a private/community water source. However, low probability of exposure because the majority of private/community wells in the area are closed and alternate sources of water are available. • Groundwater possibly influenced by (1) potential for contaminants to have moved into the area due to past on-base industrial activities; and (2) potential leakage of USZ water (along margin) into the LSZ. (Contaminants from the former off-base paint shop may also occur in the area.) • LSZ wells selected for risk assessment are on the fringes of or just outside of the Building 3001 50-year capture zone (the area that will contribute water to the system over a 50-year period) and within the containment zone (the area that will contribute water beyond the 50-year period). • Northward flow limited by the groundwater flow divides and the topographic high (north of the IWTP), and the Building 3001 extraction system. Thus, most groundwater expected to move back towards the base and extraction system.
	TOB-1 B TOB-10 AR	On base On base	No	• TOB-1 B was dry; no data available. • TOB-10 AR was obstructed and could not be sampled. (Well had previously been referred to as TOB-10 A.)
3 USZ Monitoring Wells, South of Groundwater Flow Boundary, Kimsey Addition (wells represent layer 1)	TOB-5 B TOB-6 B TOB-10 B	On base On base On base	Yes	• Wells are located within residential area at northeastern base boundary (north of industrial area of the base). • Potential for current and future use of water as a private/community water source. However, low probability of exposure because (1) the majority of private/community wells in the area are closed; (2) alternate sources of water are available; (3) the USZ is predominantly found on base and is not used as a water source (e.g., low yield and naturally high chloride and sulfate levels); and (4) private wells primarily withdraw water from the upper elevations of the LSZ (although possible that some private wells may be screened at more shallow depths than the LSZ). • Groundwater possibly influenced by (1) potential for contaminants to have moved into the area due to past on-base industrial activities; and (2) potential leakage of USZ water (along margin) into the LSZ. (Contaminants from the former off-base paint shop may also occur in the area.)
24 LSZ Monitoring Wells, South of Groundwater Flow Boundary, East of East Drive (wells represent layers 3, 5, 7, and 9)	1-49 AR, B, C 1-50 AR, BR, CR 1-51 AR, B, C 1-53 A, B, C 1-59 AR, CR 1-68 A, B, C 21 AR, C, D 22 A, B, DR, ER	On base On base On base On base On base On base On base On base	Yes	• Wells are located within an industrialized area on base, adjacent to the northeastern base boundary. • Potential for future use of water. However, low probability of exposure because the majority of private/community wells in area are closed and alternate sources of water are available. • Groundwater possibly influenced by (1) some potential for flow from the IWTP area through well clusters 1-49, 1-50, 1-51, 1-53, and 1-59; (2) water loss from Soldier Creek (area is downgradient from creek); and (3) movement of USZ water into LSZ. • Northward flow limited by the groundwater flow divides and the topographic high (north of the IWTP), and the Building 3001 extraction system.
	TOB-18 AR, B, CR TOB-19 A, B, C 23 A, BR	Off base Off base On base	No	• TOB-18 and 19 well clusters are hydraulically upgradient of the base and Soldier Creek. • Wells 23 A and BR are hydraulically upgradient of Soldier Creek.
3 USZ Monitoring Wells, South of Groundwater Flow Boundary, East of East Drive	1-59 B 19 BR 21 BR	On base On base On base	No	• The USZ is within the base boundary within this area. USZ not used as a base water supply (e.g., low yield and naturally high chloride and sulfate levels). Also, because alternate sources of water are available from surrounding municipal water supplies, unlikely that a future water well for drinking or other domestic purposes would be placed in the USZ. • Area represents potential environmental concerns due to leakage of USZ water to Soldier Creek via man-made conduits or discontinuities in the upper shale. However, this potential is evaluated under other investigations (Woodward-Clyde, 1994, 1995, 1996).
	20 BR	On base	No	• Well was dry; no data available.
2 Production Zone Monitoring Wells (wells represent layer 11)	1-50 DR 1-71 D	On base On base	Yes	• Wells potentially contaminated due to the slight potential for leakage of contaminants through the discontinuous overlying shale layers. • Current and potential future use of water.

Table 2.1. continued

Conceptual Model Well Group	Well Numbers	Well Location Relative to Base Boundary	Wells Retained or Excluded in Baseline Risk Assessment*	Rationale for Well Selection
52 LSZ Monitoring Wells, North of Groundwater Flow Boundary (wells represent layers 3, 5, 7, and 9)	1-52 A, B, C 1-71 A, B, C 1-81 A, B, C 1-82 A, B, C 1-83 A, B, C 1-84 A, B, C 1-85 A, B, C 1-86 A, B, C 1-87 A, B, C TOB-2 A, B, CR TOB-8 A, CR TOB-9 A, C TOB-11 A, B, CR TOB-12 A, B, CR TOB-13 A, BR, C TOB-15 A, B, CR TOB-16 A, B, CR TOB-20 AR, B, CR	On base On base Off base Off base Off base Off base Off base Off base Off base On base Off base Off base Off base Off base Off base Off base Off base Off base	Yes	• Slight potential for contaminant migration to the area: (1) potential lateral movement of groundwater within layers and vertical movement across layers; (2) location of layer 3 divide in the IWTP area allowing potential flow to the north; and (c) infiltration of surface water to groundwater from influent areas of Soldier Creek. • Potential current and future use of water as a private/community water source. However, low probability of exposure because the majority of private/community wells in the area are closed and alternate sources of water are available.
46 LSZ Monitoring Wells, North of Groundwater Flow Boundary Subgroup of the 52 wells (listed above)	1-52 A, B, C 1-71 A, B, C 1-81 A, B, C 1-82 A, B, C 1-83 A, B, C 1-84 A, B, C 1-85 A, B, C 1-86 A, B, C 1-87 A, B, C TOB-2 A, B, CR TOB-8 A, CR TOB-9 A, C TOB-11 A, B, CR TOB-12 A, B, CR TOB-13 A, BR, C TOB-20 AR, B, CR	On base On base Off base Off base Off base Off base Off base Off base Off base On base Off base Off base Off base Off base Off base Off base	Yes	• Subgroup of the 52 wells (listed above); thus, same rationale for the slight potential for contaminant migration to the area. Also, same criteria for low potential for exposure. • Wells evaluated as a subgroup in the risk assessment based on evidence of off-base sources of contamination near and upgradient of two of the well clusters included in the group of 52 wells (well clusters TOB-15 and TOB-16). • Off-base sources of groundwater contamination found to be related to gasoline/petroleum releases from four gasoline stations (two inactive) located at the intersection of S.E. 29th Street and Douglas Boulevard (ATSDR, 1995). • Possible, in the past, one (or more) of the gas stations was also a repair shop (i.e., chlorinated solvents may have been used for degreasing purposes). • Dry-cleaning facility near this intersection could also be a source for solvent contamination in the local vicinity. • Groundwater contaminants historically associated with the off-base sources of contamination include: TCE; PCE; *cis*-1,2-DCE; 1,2-DCA (fuel additive); TPH; total phenols; chlorobenzene; and BTEX constituents. • Off-base groundwater contamination in the area is disassociated from the base. (1) no corresponding contaminant plume from Tinker AFB to this area; (2) area is well north of the LSZ groundwater divides for all layers (layers 3, 5, 7, and 9); and (3) Soldier Creek does not discharge to groundwater in this area; thus, the creek is not a source of the groundwater contamination.
12 Residential Wells	RW-1 RW-2 RW-3 RW-4 RW-5 RW-6 RW-7 RW-8 RW-9 RW-10 RW-11 RW-12	Off base Off base Off base Off base Off base Off base Off base Off base Off base Off base Off base Off base	No	• Under the RI effort (Parsons ES, 1996a), 21 new wells were installed in the vicinity of off-base private wells to be representative of groundwater in off-base residential locations. • Significant organic contamination was found in only one private well (RW-5). Off-base sources of groundwater contamination identified near this well by the Oklahoma Corporation Commission were related to the gasoline/petroleum releases from the four gasoline stations (ATSDR, 1995). RW-5 is east of one of the gas stations; groundwater flow is to the east-northeast from the gas stations to the well (Parsons ES, 1996a).
40 Monitoring Wells Associated with Building 3001	1-1 A, BR 1-10 AR, BR, CR 1-11 A, BR, C 1-60 A, B, CR 1-64 A, B, C, D 1-70 A, B, C, D 1-75 A, B, C, D 1-76 A, B, C 19 A, CR, D 20 A, C, D 34 A, B, CR, DR 35 A, BR, C, D	On base On base On base On base On base On base On base On base On base On base On base On base	No	• Includes wells or well clusters associated with Building 3001, including wells located within the Building 3001 capture area (1-11, 1-60, 1-64, 1-70, 19, 20, 34, 35) and/or wells evaluated in the Building 3001 risk assessment (1-1, 1-10, 1-11, 19, 20, 34, 35). ** • Clusters 1-75 and 1-76 are northwest of Building 3001 and associated with Building 3001 contamination; 1-75 is located at boundary of capture zone. • Clusters 1-64 and 34 were used for water level measurements only; no chemistry data collected.

* Some wells selected for risk assessment (within the Kimsey Addition neighborhood and within the IWTP area) are within the Building 3001 capture zone, but were selected for other reasons (see rationale for these well groups). In these areas, wells were selected near the periphery of the capture zone. Wells not selected for risk assessment are listed as a separate group of wells or following the group of wells in which they are most closely associated (e.g., located within the same general area as a group of wells or sharing similar hydrologic features as a group of wells).

** COE, 1988. Risk Assessment of the Building 3001 Site, Tinker Air Force Base, Oklahoma (final report). U.S. Army Corps of Engineers, Tulsa District. Installation Restoration Program, Project No. WWYK 86-311. August 1988.

Table 2.2 Concentration Values (Detected Concentrations or Sample Quantitation Limits) for Sixteen LSZ Monitoring Wells South of Groundwater Flow Boundary (Kimsey Addition) *

Location	1-116A	1-116B	1-116C	TOB-1AR	TOB-1C	TOB-3AR	TOB-3B	TOB-3C	TOB-4A	TOB-4BR	TOB-4C	TOB-5A	TOB-5CR	TOB-6A	TOB-6C	TOB-10CR
Sample Collection Date	3-10-95	3-9-95	3-9-95	2-25-95	2-25-95	2-21-95	2-21-95	2-21-95	3-1-95	3-10-95	3-10-95	2-25-95	2-26-95	3-8-95	3-8,3-10,95	3-10-95
LSZ Layer	5	3	7	5	9	5	3	9	5	3	9	5	7	5	7	7
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles																
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 10	3	< 1
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 30	130	< 3
Chloroform	< 3	0.92	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	3	< 3	< 30	< 3	< 3
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 30	20	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 30	1.6	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 30	8	< 3
1,1-Dichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1	< 30	13	< 3
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1	< 30	3	< 3
cis-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	2.7	< 3	< 3	< 3	24	< 30	62	1.02
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1	< 30	< 3	< 3
1,2-Dichloropropane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 30	5	< 3
Methylene chloride	< 5	< 5	3	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 50	5	< 5
Tetrachloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	15	< 30	12	< 3
Trichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	2.4	< 3	< 3	< 3	26	< 30	14	1.1
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 20	120	< 2
Semivolatiles																
Benzoic acid	< 10	< 10	< 10	NS	NS	NS	NS	NS	NS	< 10	< 10	NS	NS	NS	22	< 10
Bis(2-ethylhexyl)phthalate	< 27	< 17	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 32	59	< 10	< 10	< 10	< 16	< 10
2-Chlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	3	23	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	2	< 10
1,4-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1	9	< 10
Total Metals																
Arsenic	< 5	7.6	4.3	5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	16
Barium	440	380	500	530	640	730	1500	540	170	340	200	350	140	210	410	990
Chromium (total)	< 20	5	6	6	5	< 20	< 20	< 20	< 20	450	< 20	< 20	< 20	16	42	< 20
Copper	< 20	11	< 20	< 20	< 20	< 20	< 20	< 20	7	42	8	< 20	< 20	< 20	< 20	< 20
Lead	< 5	2.5	< 5	< 5	< 5	< 5	1	1.17	< 5	1.97	< 5	< 5	< 5	< 5	< 5	< 5
Nickel	6	12	< 20	< 20	< 20	< 20	< 20	< 20	< 20	570	< 20	< 20	< 20	22	35	< 20
Silver	< 20	< 20	< 20	< 20	< 20	14	14	13	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Zinc	< 10	< 10	< 10	< 10	11	< 10	< 10	< 10	< 23	77	< 10	< 10	< 10	< 10	< 10	< 10

* Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample.

- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.3 Concentration Values (Detected Concentrations or Sample Quantitation Limits) for Twenty-four LSZ Monitoring Wells South of Groundwater Flow Boundary (East of East Drive)*

Location	1-49AR	1-49B	1-49C	1-50AR	1-50BR	1-50CR	1-51AR	1-51B	1-51C	1-53A	1-53B	1-53C
Sample Collection Date	3-11-95	3-12-95	3-11-95	3-13-95	3-13-95	3-13-95	3/12/1995	3/12/1995	3/12/1995	3/12/1995	3/12/1995	3/12/1995
LSZ Layer	5	3	7	5	3	7	5	3	7	5	3	7
Concentration Units	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Volatiles												
Benzene	< 1	< 3	< 1	9	5	< 1	2	<1	0.99	<1	<1	<1
Bromodichloromethane	< 3	< 8	< 3	< 15	< 8	< 3	<6	1.1	<3	<3	<3	<3
Carbon tetrachloride	NA	NA	NA	NA	NA	NA	<6	<3	<3	<3	<3	<3
Chlorobenzene	4	< 8	< 3	580	250	2.4	260	<3	200	<3	<3	<3
Chloroform	< 3	< 8	< 3	< 15	< 8	< 3	<6	4	<3	<3	<3	1
Chloromethane	NA	NA	NA	NA	NA	NA	<20	<10	<10	<10	<10	<10
1,2-Dichlorobenzene	2	< 8	< 3	240	6	1.3	61	<3	22	<3	<3	<3
1,3-Dichlorobenzene	< 3	< 8	< 3	7	< 8	< 3	1.8	<3	2.5	<3	<3	<3
1,4-Dichlorobenzene	< 3	< 8	< 3	84	6	< 3	35	<3	22	<3	<3	<3
1,1-Dichloroethane	1.8	4	< 3	40	14	< 3	5.6	<3	2.3	<3	<3	<3
1,2-Dichloroethane	< 1	< 3	3	< 5	< 3	< 1	<2	<1	<1	<1	<1	<1
1,1-Dichloroethene	2.7	18	< 3	17	27	< 3	3.1	<3	<3	<3	<3	<3
cis-1,2-Dichloroethene	55	23	36	850	340	8	190	<3	11	<3	<3	1.7
trans-1,2-Dichloroethene	1.2	< 8	1.6	11	< 8	< 3	2.7	<3	<3	<3	<3	<3
1,2-Dichloropropane	1.7	< 8	< 3	25	< 8	< 3	2.5	<3	<3	<3	<3	<3
Methylene chloride	NA	NA	NA	NA	NA	NA	2.2	<3	<3	<5	<5	<5
Tetrachloroethene	8	330	4	75	37	< 3	21	<3	<3	<3	<3	<3
Toluene	NA	NA	NA	NA	NA	NA	<6	<3	<3	<3	<3	<3
1,1,1-Trichloroethane	< 3	2.6	< 3	< 15	19	< 3	<6	<3	<3	<3	<3	<3
Trichloroethene	44	51	37	380	16	4	56	<3	4	<3	<3	1.9
Trichlorofluoromethane	< 3	< 8	< 3	< 15	< 8	< 3	<6	<3	<3	<3	<3	<3
Vinyl chloride	< 2	< 5	< 2	610	150	< 2	64	<2	16	<2	<2	<2
Xylenes	NA	NA	NA	NA	NA	NA	<6	<3	<3	<3	<3	<3
Semivolatiles												
Bis(2-ethylhexyl)phthalate	NA	NA	NA	NA	NA	NA	<10	<10	<10	<10	<10	14
2-Chloronaphthalene	< 10	< 10	< 10	< 10	10	< 10	NA	NA	NA	<10	<10	<10
1,2-Dichlorobenzene	2	< 10	< 10	380	7	< 10	89	<10	31	<10	<10	<10
1,3-Dichlorobenzene	< 10	< 10	< 10	10	< 10	< 10	3	<10	3	<10	<10	<10
1,4-Dichlorobenzene	< 10	< 10	< 10	110	8	< 10	49	<10	27	<10	<10	<10
Fluoranthene	NA	NA	NA	NA	NA	NA	<10	<10	<10	<10	<10	<10
Naphthalene	NA	NA	NA	NA	NA	NA	<10	<10	<10	<10	<10	<10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	<10	<10	<10	<10	<10	<10
Pesticides												
Aldrin	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
alpha-BHC	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
beta-BHC	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
gamma-BHC	0.09	< 0.01	NS	< 0.01	< 0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4-4'-DDD	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4-4'-DDE	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
4-4'-DDT	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dieldrin	< 0.01	< 0.01	NS	< 0.01	< 0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endosulfan I	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Endrin	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Heptachlor	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Heptachlor epoxide	NA	NA	NA	NA	NA	NA	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Metals												
Arsenic	< 5	< 5	< 5	< 5	< 5	< 5	<5	<5	<5	<5	<5	<5
Barium	660	79	940	1300	400	740	1100	140	1400	1300	400	810
Beryllium	NA	NA	NA	NA	NA	NA	NS	NS	NS	NS	NS	NS
Cadmium	< 5	< 5	< 5	3	< 5	< 5	<5	<5	<5	<5	<5	<5
Chromium (total)	7	48	< 20	< 20	< 20	< 20	<20	14	<20	10	14	<20
Chromium VI	NA	NA	NA	NA	NA	NA	<60	<60	<60	<60	<60	<60
Copper	NA	NA	NA	NA	NA	NA	<20	<20	<20	<20	<20	<20
Lead	NA	NA	NA	NA	NA	NA	<5	<5	<5	<5	<5	2.3
Nickel	24	350	< 20	140	62	9	31	<20	59	12	180	6
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	<10	<10	<10	<10	<10	<10
Silver	NA	NA	NA	NA	NA	NA	<20	<20	<20	<20	<20	<16
Thallium	NA	NA	NA	NA	NA	NA	NS	NS	NS	NS	NS	NS
Zinc	< 10	< 10	< 10	< 9	< 8	< 12	<10	<10	<10	<10	<10	<15

* Value shown is either the detected concentration or the SQL (shown as < value).

NS - No sample.

NA - Not available

- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.3 (cont.) Concentration Values (Detected Concentrations or Sample Quantitation Limits) for Twenty-four LSZ Monitoring Wells South of Groundwater Flow Boundary (East of East Drive)*

Location	1-59AR	1-59CR	1-68A	1-68B	1-68C	21AR	21C	21D	22A	22B	22DR	22ER
Sample Collection Date	3-12-95	3-12-95	2-25-95	2-25-95	2-25-95	2-25-95	2-25-95	2-25-95	2-28-95	2-28-95	2-28-95	2-26-95
LSZ Layer	5	7	7	5	9	5	7	9	5	3	5	7
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles												
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Bromodichloromethane	1.9	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chlorobenzene	2	1.4	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	73	< 3
Chloroform	57	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	21	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	0.93	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	10	< 3
1,1-Dichloroethane	4	< 3	1.9	< 3	< 3	1.6	< 3	< 3	< 3	< 3	1.8	< 3
1,2-Dichloroethane	< 1	3	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1.6	< 1
1,1-Dichloroethene	2	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	12	8	3.2	< 3	< 3	10	< 3	< 3	< 3	< 3	51	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	1.1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Tetrachloroethene	5	< 3	< 3	< 3	< 3	3.6	< 3	< 3	< 3	< 3	< 3	< 3
Toluene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Trichloroethene	7	13	3.1	< 3	< 3	60	< 3	< 3	< 3	2.8	29	< 3
Trichlorofluoromethane	< 3	< 3	< 3	< 3	< 3	1.3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	38	< 2
Xylenes	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Semivolatiles												
Bis(2-ethylhexyl)phthalate	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
2-Chloronaphthalene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	22	< 10
1,4-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	9	< 10
Fluoranthene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Naphthalene	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1
Pesticides												
Aldrin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
alpha-BHC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
beta-BHC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
gamma-BHC	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4-4'-DDD	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4-4'-DDE	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
4-4'-DDT	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dieldrin	0.02	< 0.01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Endosulfan I	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Endrin	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Heptachlor	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor epoxide	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Metals												
Arsenic	< 5	< 5	< 5	< 5	< 5	< 5	6	4.4	< 5	< 5	4	< 5
Barium	44	1220	580	100	670	800	630	520	580	370	760	1000
Beryllium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Chromium (total)	920	< 20	< 20	< 20	< 20	9	< 20	< 20	< 20	17	< 20	< 20
Chromium VI	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Copper	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lead	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nickel	7	7	< 20	< 20	< 20	< 20	< 20	< 20	< 20	10	< 20	< 20
Selenium	3.4	3.5	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Thallium	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	< 10	< 10	< 9.9	< 8.3	< 7.9	12	11	8	< 10	< 8	< 10	< 10

* Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample.
NA - Not available
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.4 Concentration Values (Detected Concentrations or Sample Quantitation Limits) for Fifty-two LSZ Monitoring Wells North of Groundwater Flow Boundary*

Location	1-52A	1-52B	1-52C	1-71A	1-71B	1-71C	1-81A	1-81B	1-81C	1-82A	1-82B
Sample Collection Date	3-12-95	3-12-95	3-12-95	2-24-95	2-24-95	2-25-95	2-22-95	2-22-95	2-22-95	2-10-95	2-11-95
LSZ Layer	5	3	7	7	3	9	7	5	9	7	5
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles											
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Bromodichloromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chlorobenzene	4	< 3	1.9	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloroform	< 3	< 3	< 3	< 3	< 3	< 3	1.1	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	2.5	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 3	< 3	1.1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,4-Dichlorobenzene	1.1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1-Dichloroethane	2.1	< 3	1.2	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloroethane	< 1	< 1	0.92	< 1	< 1	< 1	1	< 1	< 1	< 1	0.9
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	< 3	< 3	5	< 3	< 3	< 3	4.9	< 3	< 3	< 3	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Tetrachloroethene	< 3	< 3	1.6	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Toluene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	0.9	< 3	< 3
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Trichloroethene	2.3	< 3	5	< 3	2	< 3	5.3	< 3	< 3	< 3	1
Trichlorofluoromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Xylenes	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Semivolatiles											
Bis(2-ethylhexyl)phthalate	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 13	< 10	< 10	< 10
1,2-Dichlorobenzene	1	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,4-Dichlorobenzene	1	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Fluoranthene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Naphthalene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pesticides											
Aldrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
alpha-BHC	< 0.01	0.04	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
beta-BHC	< 0.01	0.18	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	0.01
gamma-BHC	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	0.005	0.004	< 0.01
4,4'-DDD	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
4,4'-DDE	< 0.01	< 0.01	< 0.01	NS	NS	NS	0.006	< 0.01	< 0.01	< 0.01	< 0.01
4,4'-DDT	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dieldrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	0.007	< 0.01
Endosulfan I	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Endrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Heptachlor	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Heptachlor epoxide	< 0.01	< 0.01	< 0.01	NS	NS	NS	0.002	< 0.01	< 0.01	< 0.01	< 0.01
Total Metals											
Arsenic	< 5	< 5	< 5	< 5	< 5	4.6	< 5	< 5	< 5	< 5	< 5
Barium	150	150	860	580	93	810	270	79	495	430	1000
Beryllium	NS	NS	NS	NS	NS	NS	< 2	< 2	2.6	< 2	< 2
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	3.9	< 5	< 5
Chromium (total)	< 20	7	5	< 20	< 20	< 20	6.6	97	5.2	< 20	< 20
Chromium VI	< 60	< 60	< 60	< 60	< 60	< 60	< 60	200	< 60	< 60	< 60
Copper	< 20	< 20	< 20	< 20	< 20	< 20	4.6	9	< 20	< 8	< 5.6
Lead	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	2.2	0.9	0.8
Nickel	27	16	30	< 20	12	< 20	< 20	157	< 20	< 20	< 20
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	< 20	< 20	< 20	30	35	< 20	< 20	< 20	< 20	< 11	< 26
Thallium	NS	NS	NS	NS	NS	NS	NS*	NS*	NS*	< 5	< 5
Zinc	< 10	< 10	< 10	180	< 11	8.3	< 22	75	< 42	< 26	< 64

* Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample
NS* - Sampled and analyzed, but based on EPA National Functional Guidelines, the data is considered NS.
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.4, continued

Location	1-82C	1-83A	1-83B	1-83C	1-84A	1-84B	1-84C	1-85A	1-85B	1-85C	1-86A
Sample Collection Date	2-10-95	2-13-95	2-13-95	2-11-95	2-11-95	2-11-95	2-10-95	2-20-95	2-20-95	2-20-95	2-13-95
LSZ Layer	9	7	5	9	7	3	9	5	3	7	7
Concentration Units	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Volatiles											
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	38	< 1	< 1	< 1
Bromodichloromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	< 3	< 3	< 3	< 3	< 3	1.1	< 3	< 3	< 3	< 3	< 3
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloroform	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1.8	< 10
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1-Dichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloroethane	< 1	1.4	< 1	< 1	< 1	< 1	< 1	< 1.1	< 1	< 1	0.9
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	< 3	< 3	< 3	< 3	1.1	< 3	< 3	< 3	< 3	1.1	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Tetrachloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Toluene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1	< 3
Trichloroethene	< 3	< 3	< 3	< 3	1.7	< 3	< 3	< 3	< 3	< 3	< 3
Trichlorofluoromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Xylenes	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1.3	< 3	< 3	< 3
Semivolatiles											
Bis(2-ethylhexyl)phthalate	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,4-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Fluoranthene	< 10	< 10	< 10	< 10	< 10	< 10	1	< 10	< 10	< 10	< 10
Naphthalene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1	< 10	< 10
Pesticides											
Aldrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
alpha-BHC	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.01	< 0.01	< 0.01	< 0.01
beta-BHC	0.01	< 0.01	< 0.01	0.02	< 0.01	0.06	0.02	0.01	< 0.01	< 0.01	0.03
gamma-BHC	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
4,4'-DDD	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.003
4,4'-DDE	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
4,4'-DDT	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dieldrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.004	0.002	< 0.01	< 0.01	< 0.01	< 0.01
Endosulfan I	< 0.01	< 0.01	< 0.01	0.003	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.004	< 0.01
Endrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.002	< 0.01
Heptachlor	0.009	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Heptachlor epoxide	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.005	< 0.01	< 0.01	0.003	< 0.01	0.002
Total Metals											
Arsenic	< 5	< 5	< 5	5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Barium	620	450	310	750	320	460	600	640	79	570	810
Beryllium	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Chromium (total)	< 20	< 20	< 20	< 20	< 20	39	< 20	< 20	24	< 20	< 20
Chromium VI	< 60	< 60	< 60	< 60	< 60	440	< 60	< 60	< 60	< 60	< 60
Copper	< 15	< 76	< 20	< 20	< 3.6	< 6.4	< 17	< 20	10	4	< 3.6
Lead	1.3	< 5	< 5	< 5	1.1	< 5	4.9	< 1.5	< 1.4	< 2	13
Nickel	< 20	< 20	< 17	< 20	< 33	360	< 20	< 20	290	< 20	< 29
Selenium	< 10	< 10	< 10	< 10	1.5	< 10	< 10	< 10	2.5	< 10	< 10
Silver	< 20	< 32	< 32	< 10	< 19	< 19	< 15	< 20	10	< 20	< 33
Thallium	< 5	< 5	< 5	5	2.4	< 5	< 5	NS*	NS*	NS*	< 5
Zinc	< 35	< 26	< 23	< 19	< 44	< 15	< 200	< 20	< 14	< 18	< 16

* Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample
NS* - Sampled and analyzed, but based on EPA National Functional Guidelines, the data is considered NS.
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.4. continued

Location	1-86B	1-86C	1-87A	1-87B	1-87C	TOB-2A	TOB-2B	TOB-2CR	TOB-8A	TOB-8CR	TOB-9A
Sample Collection Date	2-14-95	2-13-95	2-14-95	2-14-95	2-14-95	2-23-95	2-23-95	2-23-95	2-14-95	2-14-95	2-22-95
LSZ Layer	3	9	7	5	9	7	3,5	9	5	7	5
Concentration Units	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Volatiles											
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Bromodichloromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloroform	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	0.9	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1-Dichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloroethane	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1.4	1	< 1
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	5.2	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Tetrachloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Toluene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Trichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	11	< 3
Trichlorofluoromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Xylenes	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Semivolatiles											
Bis(2-ethylhexyl)phthalate	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,4-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Fluoranthene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Naphthalene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	2	< 10	< 10	< 10	< 10	< 10
Pesticides											
Aldrin	< 0.01	0.006	< 0.01	< 0.01	0.01	NS	NS	NS	NS	NS	NS
alpha-BHC	< 0.01	0.01	0.006	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
beta-BHC	0.01	< 0.01	0.03	0.03	0.04	NS	NS	NS	NS	NS	NS
gamma-BHC	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
4,4'-DDD	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
4,4'-DDE	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
4,4'-DDT	< 0.01	< 0.01	0.004	< 0.01	0.008	NS	NS	NS	NS	NS	NS
Dieldrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
Endosulfan I	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
Endrin	< 0.01	< 0.01	< 0.01	< 0.01	0.002	NS	NS	NS	NS	NS	NS
Heptachlor	< 0.01	< 0.01	< 0.01	< 0.01	0.009	NS	NS	NS	NS	NS	NS
Heptachlor epoxide	< 0.01	< 0.01	0.002	< 0.01	< 0.01	NS	NS	NS	NS	NS	NS
Total Metals											
Arsenic	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Barium	1200	550	400	650	600	270	400	490	130	710	430
Beryllium	< 2	< 2	< 2	< 2	< 2	NS	NS	NS	NS	NS	NS
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Chromium (total)	< 20	< 20	< 20	< 20	< 20	< 20	< 20	4.7	5	< 20	4.6
Chromium VI	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60
Copper	8	110	< 20	3.4	< 20	< 20	< 20	< 20	8	< 20	< 20
Lead	< 2.88	7	< 1.33	< 1.59	< 1.89	< 5	< 5	< 5	< 4.04	< 5	< 5
Nickel	< 20	< 20	< 20	< 20	13	< 20	< 20	< 20	< 20	< 20	< 20
Selenium	2.49	1.6	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	< 20	< 30	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Thallium	NS*	< 5	NS*	NS*	NS*	NS	NS	NS	NS	NS	NS
Zinc	< 8	< 22	< 13	< 22	< 17	< 10	10	< 10	43	< 4.9	< 14

* Value shown is either the detected concentration or the SQL (shown as < value).

NS - No sample

NS* - Sampled and analyzed, but based on EPA National Functional Guidelines, the data is considered NS.

- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.4, continued

Location	TOB-9C	TOB-11A	TOB-11B	TOB-11CR	TOB-12A	TOB-12B	TOB-12CR	TOB-13A	TOB-13BR	TOB-13C	TOB-15A
Sample Collection Date	2-22-95	2-21-95	2-21-95	2-21-95	2-21-95	2-21-95	2-21-95	2-24-95	2-15-95	2-15-95	2-20-95
LSZ Layer	7	7	3	9	7	5	9	7	5	9	7
Concentration Units	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Volatiles											
Benzene	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Bromodichloromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	1.4	< 3	< 3	< 3	< 3	1.5
Chloroform	< 3	1.1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1.3	< 10
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1-Dichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloroethane	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	< 3	1.1	< 3	< 3	< 3	< 3	< 3	12	< 3	< 3	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Tetrachloroethene	< 3	2.3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1.4
Toluene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Trichloroethene	< 3	4.7	< 3	< 3	< 3	< 3	< 3	3	< 3	< 3	< 3
Trichlorofluoromethane	< 3	1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Xylenes	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Semivolatiles											
Bis(2-ethylhexyl)phthalate	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,4-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Fluoranthene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Naphthalene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pesticides											
Aldrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
alpha-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
beta-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
gamma-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDE	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Dieldrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Endosulfan I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Endrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor epoxide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total Metals											
Arsenic	< 5	< 5	< 5	< 5	11	< 5	< 5	< 5	< 5	< 5	< 5
Barium	832	480	160	610	98	1100	56	1100	260	710	990
Beryllium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	4	< 5	< 5
Chromium (total)	< 20	< 20	< 20	6	< 20	< 20	< 20	< 20	8	< 20	< 20
Chromium VI	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60
Copper	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	7	< 20	< 20
Lead	< 5	< 5	< 5	1	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Nickel	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	8	< 20	< 20
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	2.4	< 10	< 10
Silver	< 20	< 20	15	11	9	28	12	< 20	< 20	< 20	8
Thallium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc	< 7.9	< 10	9	10	8	13	< 10	< 10	< 10	< 10	< 10

* Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.4, continued

Location	TOB-15B	TOB-15CR	TOB-16A	TOB-16B	TOB-16CR	TOB-20AR	TOB-20B	TOB-20CR
Sample Collection Date	2-20-95	2-20-95	2-12-95	2-14-95	2-20-95	2-21-95	2-23-95	2-21-95
LSZ Layer	5	9	7	7	9	7	5	9
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles								
Benzene	26	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Bromodichloromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Carbon tetrachloride	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chlorobenzene	< 3	< 3	3.4	< 3	< 3	< 3	< 3	< 3
Chloroform	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1.7
1,2-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,3-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,4-Dichlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	1	< 3
1,1-Dichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloroethane	96	< 1	< 1	< 1	< 1	< 1	< 1	< 1
1,1-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
cis-1,2-Dichloroethene	< 3	2.4	1	< 3	< 3	< 3	< 3	< 3
trans-1,2-Dichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,2-Dichloropropane	2.2	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Methylene chloride	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Tetrachloroethene	< 3	< 3	< 3	20	< 3	< 3	< 3	< 3
Toluene	2.9	< 3	< 3	< 3	< 3	< 3	< 3	< 3
1,1,1-Trichloroethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Trichloroethene	< 3	1.5	< 3	< 3	< 3	< 3	< 3	< 3
Trichlorofluoromethane	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Vinyl chloride	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2
Xylenes	4.3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Semivolatiles								
Bis(2-ethylhexyl)phthalate	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,3-Dichlorobenzene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,4-Dichlorobenzene	< 10	< 10	1	< 10	< 10	< 10	< 10	< 10
Fluoranthene	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Naphthalene	1	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pentachlorophenol	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Pesticides								
Aldrin	NS	NS	NS	NS	NS	NS	NS	NS
alpha-BHC	NS	NS	NS	NS	NS	NS	NS	NS
beta-BHC	NS	NS	NS	NS	NS	NS	NS	NS
gamma-BHC	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDD	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDE	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDT	NS	NS	NS	NS	NS	NS	NS	NS
Dieldrin	NS	NS	NS	NS	NS	NS	NS	NS
Endosulfan I	NS	NS	NS	NS	NS	NS	NS	NS
Endrin	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor epoxide	NS	NS	NS	NS	NS	NS	NS	NS
Total Metals								
Arsenic	< 5	< 5	< 5	< 5	< 5	< 5	7	< 5
Barium	550	530	790	330	580	500	800	430
Beryllium	NS	NS	NS	NS	NS	NS	NS	NS
Cadmium	5	< 5	< 5	< 5	< 5	3	< 5	< 5
Chromium (total)	< 20	< 20	< 20	4.7	< 20	< 20	< 20	< 20
Chromium VI	< 60	< 60	< 60	< 60	< 60	< 60	< 60	< 60
Copper	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Lead	1.15	< 5	0.8	< 1.22	< 5	1.03	< 1.7	< 5
Nickel	< 20	< 20	< 32	< 20	36	< 20	19.6	< 20
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	14	< 20	< 25	< 20	16	19	< 20	< 20
Thallium	NS	NS	NS	NS	NS	NS	NS	NS
Zinc	< 10	< 9	< 22	< 10	8	16	< 12	9

* Value shown is either the detected concentration or the SQL (shown as < value).

NS - No sample

- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.5 Concentration Values (Detected Concentrations or Sample Quantitatiion Limits) for Subgroup of Forty-six LSZ Monitoring Wells North of Groundwater Flow Boundary

Location	1-52A	1-52B	1-52C	1-71A	1-71B	1-71C	1-81A	1-81B	1-81C	1-82A	1-82B	1-82C	1-83A	1-83B	1-83C	1-84A
Sample Collection Date	3-12-95	3-12-95	3-12-95	2-24-95	2-24-95	2-25-95	2-22-95	2-22-95	2-22-95	2-10-95	2-11-95	2-10-95	2-13-95	2-13-95	2-11-95	2-11-95
LSZ Layer	5	3	7	7	3	9	7	5	9	7	5	9	7	5	9	7
Concentration Units	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L	μg/L
Volatiles																
Chlorobenzene	4	< 3	1.9	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	2.5	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichloroethane	< 1	< 1	0.92	< 1	< 1	< 1	1	< 1	< 1	< 1	0.9	< 1	1.4	< 1	< 1	< 1
cis-1,2-Dichloroethene	< 3	< 3	5	< 3	< 3	< 3	4.9	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	1.1
Trichloroethene	2.3	< 3	5	< 3	2	< 3	5.3	< 3	< 3	< 3	1	< 3	< 3	< 3	< 3	1.7
Pesticides																
Aldrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
alpha-BHC	< 0.01	0.04	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
beta-BHC	< 0.01	0.18	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	< 0.01	< 0.01	0.02	< 0.01
gamma-BHC	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	0.005	0.004	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
4,4'-DDT	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Dieldrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	0.007	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Endosulfan I	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.003	< 0.01
Endrin	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Heptachlor	< 0.01	< 0.01	< 0.01	NS	NS	NS	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.009	< 0.01	< 0.01	< 0.01	< 0.01
Heptachlor epoxide	< 0.01	< 0.01	< 0.01	NS	NS	NS	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Total Metals																
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	3.9	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Copper	< 20	< 20	< 20	< 20	< 20	< 20	4.6	9	< 20	< 8	< 5.6	< 15	< 76	< 20	< 20	< 3.6
Nickel	24	16	30	< 20	12	< 20	< 20	157	< 20	< 20	< 20	< 20	< 20	< 17	< 20	< 33
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1.5
Silver	< 20	< 20	< 20	30	35	< 20	< 20	< 20	< 20	< 11	< 26	< 20	< 32	< 32	< 10	< 19
Thallium	NS	NS	NS	NS	NS	NS	NS*	NS*	NS*	< 5	< 5	< 5	< 5	< 5	5	2.4
Zinc	< 10	< 10	< 10	180	< 11	8.3	< 22	75	< 42	< 26	< 64	< 35	< 26	< 23	< 19	< 44

Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample.
NS* - Sampled but data are considered as NS.
For samples with field duplicates: (1) average concentration used when analyte detected in both samples; (2) detected concentration used when analyte detected in only one sample; or (3) lowest SQL used when analyte not detected in either sample and when SQLs differ.
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.5, continued

Location	1-84B	1-84C	1-85A	1-85B	1-85C	1-86A	1-86B	1-86C	1-87A	1-87B	1-87C	TOB-2A	TOB-2B	TOB-2CR	TOB-8A	TOB-8CR
Sample Collection Date	2-11-95	2-10-95	2-20-95	2-20-95	2-20-95	2-13-95	2-14-95	2-13-95	2-14-95	2-14-95	2-14-95	2-23-95	2-23-95	2-23-95	2-14-95	2-14-95
LSZ Layer	3	9	5	3	7	7	3	9	7	5	9	7	3	9	5	7
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles																
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	1.8	< 10	< 10	< 10	< 10	0.9	< 10	< 10	< 10	< 10	< 10	< 10
1,2-Dichloroethane	< 1	< 1	< 1.1	< 1	< 1	0.9	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	1.4	1
cis-1,2-Dichloroethene	< 3	< 3	< 3	< 3	1.1	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	5.2
Trichloroethene	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	11
Pesticides																
Aldrin	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.006	< 0.01	< 0.01	0.01	NS	NS	NS	NS	NS
alpha-BHC	< 0.01	0.006	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.006	< 0.01	< 0.01	NS	NS	NS	NS	NS
beta-BHC	0.06	0.02	0.01	< 0.01	< 0.01	0.03	0.01	< 0.01	0.03	0.03	0.04	NS	NS	NS	NS	NS
gamma-BHC	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS
4,4'-DDT	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.004	< 0.01	0.008	NS	NS	NS	NS	NS
Dieldrin	0.004	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS
Endosulfan I	< 0.01	< 0.01	< 0.01	< 0.01	0.004	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	NS	NS	NS	NS	NS
Endrin	< 0.01	< 0.01	< 0.01	< 0.01	0.002	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.002	NS	NS	NS	NS	NS
Heptachlor	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.009	NS	NS	NS	NS	NS
Heptachlor epoxide	0.005	< 0.01	< 0.01	0.003	< 0.01	0.002	< 0.01	< 0.01	0.002	< 0.01	< 0.01	NS	NS	NS	NS	NS
Total Metals																
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5
Copper	< 6.4	< 17	< 20	10	4	< 3.6	8	110	< 20	3.4	< 20	< 20	< 20	< 20	8	< 20
Nickel	360	< 20	< 20	290	< 20	< 29	< 20	< 20	< 20	< 20	13	< 20	< 20	< 20	< 20	< 20
Selenium	< 10	< 10	< 10	2.5	< 10	< 10	2.49	1.6	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Silver	< 19	< 15	< 20	10	< 20	< 33	< 20	< 30	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20
Thallium	< 5	< 5	NS*	NS*	NS*	< 5	NS*	< 5	NS*	NS*	NS*	NS	NS	NS	NS	NS
Zinc	< 15	< 200	< 20	< 14	< 18	< 16	< 8	< 22	< 13	< 22	< 17	< 10	10	< 10	43	< 4.9

Value shown is either the detected concentration or the SQL (shown as < value).
NS - No sample.
NS* - Sampled but data are considered as NS.
For samples with field duplicates: (1) average concentration used when analyte detected in both samples; (2) detected concentration used when analyte detected in only one sample; or (3) lowest SQL used when analyte not detected in either sample and when SQLs differ.
- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

Table 2.5, continued

Location	TOB-9A	TOB-9C	TOB-11A	TOB-11B	TOB-11CR	TOB-12A	TOB-12B	TOB-12CR	TOB-13A	TOB-13BR	TOB-13C	TOB-20AR	TOB-20B	TOB-20CR
Sample Collection Date	2-22-95	2-22-95	2-21-95	2-21-95	2-21-95	2-21-95	2-21-95	2-21-95	2-24-95	2-15-95	2-15-95	2-21-95	2-23-95	2-21-95
LSZ Layer	5	7	7	3	9	7	5	9	7	5	9	7	5	9
Concentration Units	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
Volatiles														
Chlorobenzene	< 3	< 3	< 3	< 3	< 3	< 3	1.4	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Chloromethane	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	1.3	< 10	< 10	1.7
1,2-Dichloroethane	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
cis-1,2-Dichloroethene	< 3	< 3	1.1	< 3	< 3	< 3	< 3	< 3	12	< 3	< 3	< 3	< 3	< 3
Trichloroethene	< 3	< 3	4.7	< 3	< 3	< 3	< 3	< 3	3	< 3	< 3	< 3	< 3	< 3
Pesticides														
Aldrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
alpha-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
beta-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
gamma-BHC	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
4,4'-DDT	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Dieldrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Endosulfan I	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Endrin	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Heptachlor epoxide	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total Metals														
Cadmium	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	< 5	4	< 5	3	< 5	< 5
Copper	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	7	< 20	< 20	< 20	< 20
Nickel	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	< 20	8	< 20	< 20	19.6	< 20
Selenium	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	2.4	< 10	< 10	< 10	< 10
Silver	< 20	< 20	< 20	15	11	9	28	12	< 20	< 20	< 20	19	< 20	< 20
Thallium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Zinc	< 14	< 7.9	< 10	9	10	8	13	< 10	< 10	< 10	< 10	12	< 12	9

Value shown is either the detected concentration or the SQL (shown as < value).

NS - No sample.

For samples with field duplicates: (1) average concentration used when analyte detected in both samples; (2) detected concentration used when analyte detected in only one sample; or (3) lowest SQL used when analyte not detected in either sample and when SQLs differ.

- Highlights contaminants in groundwater samples which were detected at concentrations above the sample quantitation limit.

J/721447/WP/TINKFS/TBL2-5.XLS

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March 2000

Table 2.6 Qualitative Comparison for Main Compounds Contributing to Risks Within Conceptual Model Well Groups. (1)

Chemicals of Concern Exceeding Risk in at Least One Well Group	Well Groups Within Soldier Creek Conceptual Model Area: South of Groundwater Flow Boundary: Kimsey Addition 16 LSZ Wells: Avg./EC/Max. (2) (µg/L)	Kimsey Addition 16 LSZ Wells: Chemical-Specific Contribution to Risk (3)	East of East Drive 24 LSZ Wells: Avg./EC/Max. (µg/L)	East of East Drive 24 LSZ Wells: Chemical-Specific Contribution to Risk	North of Groundwater Flow Boundary: 52 LSZ Wells: Avg./EC/Max. (µg/L)	52 LSZ Wells: Chemical-Specific Contribution to Risk	Qualitative Comparison Criteria: Inorganic Background Levels (4): Central Okla. Aquifer Avg./Max. (5) (µg/L)	Soldier Creek Watershed Avg./Max. (µg/L)	Municipal Water Wells: Dell City Avg./Max. (µg/L)	Municipal Water Wells: Midwest City Avg./Max. (µg/L)	Water Quality Standards: EPA (6): MCL (µg/L)	Oklahoma (7): Drinking Water Reg. (µg/L)	Oklahoma (7): Groundwater Quality Standard (µg/L)	Inorganic Background Level LSZ for Tinker AFB Avg./Max. (µg/L)
cis-1,2-DCE	8 15 62	---	65 126 795	<1	1.9 2.3 12	---	NA	NA	NA	NA	70	70	NA	NA
	ND	---	5		*	---	NA	NA	NA	NA	1	1	NA	NA
Vinyl chloride	**9** **22** **120**	>1E-4	36 27 610	>1E-4	NA NA NA	NA	NA	NA	NA	NA	2	2	1.9	NA
	3.9 5.5 16	---	2.8 3.1 6	---	2.8 3.2 11	---	1 (--) **110**	NA	1.9 (--) 3	1.2 (--) 3	50	50	NA	3.89 20
	504 656 **1,500**	---	687 826 1,350	NA ---	520 588 1,200	---	190 (--) **6,400**	NA	487 (--) 1,002	418 (--) 510	2,000	2,000	NA	714 **4700**
	NA	---	ND NA	---	1.1 1.2 2.6	---	0.03 (--) 2.4	NA	(<2)	(<2)	4	NA	NA	NA
	39 87 $\boxed{450}$	---	50 **115** **920**	---	12 15 2.6	---	1.4 (--) 100	2.1	22 (--) 95	9.4 (--) 18	100	100	NA	60.4 **1500**
Thallium	NA	---	NA	---	**2.7** **3.1** **5**	>1	NA	NA	(<1)	(<1)	2	NA	NA	NA

(1) Main compounds contributing to risk for the five conceptual model well groups. Risk is not necessarily unacceptable.
(2) Average concentration, exposure concentration, and maximum detected concentration of main compound (by well group).
(3) Chemical-specific contribution to unacceptable cancer risk or noncancer hazard (by well group):
- > 1E-4 = chemical exceeded the upper bound of the acceptable cancer risk range;
- < 1E-4 = chemical contributed to an unacceptable total cancer risk, but individually did not exceed unacceptable level;
- > 1 = chemical exceeded the noncancer threshold level;
- < 1 = chemical contributed to systemic risk, but individually did not exceed threshold level.

(4) Data for background levels discussed in text and appendix.
(5) Average background concentration, followed by maximum background concentration. If not detected, detection limit is given (shown as "<" value).
(6) EPA, 1995b.
(7) Oklahoma Department of Environmental Quality, 1996.
--- Chemical was not a main compound contributing to risk within the specified well group.
* Average concentration and exposure concentration not applicable due to low detection frequency of the chemical.
(--) Background exposure concentrations (95% UCLs) not included for qualitative comparisons.
ND Not detected.
NA Not analyzed, or not available.

Border within "Avg./EC/Max." column denotes an average or maximum detected chemical concentration greater than three times (3x) the highest of background concentrations; for each compound, comparisons are made between the average concentration (for the well group) and the highest average background concentration, and the maximum chemical concentration (for the well group) and the highest maximum background concentration.

Shading within "Avg./EC/Max." column denotes chemical concentrations above the EPA and/or Oklahoma regulatory drinking water regulation.

Shading within "Chemical-Specific Contribution to Risk" column indicates that the chemical individually resulted in an estimated unacceptable cancer risk or noncancer hazard.

* Average is highter than maximum in Table 2 of applicable subsection of Appendix A, RA.

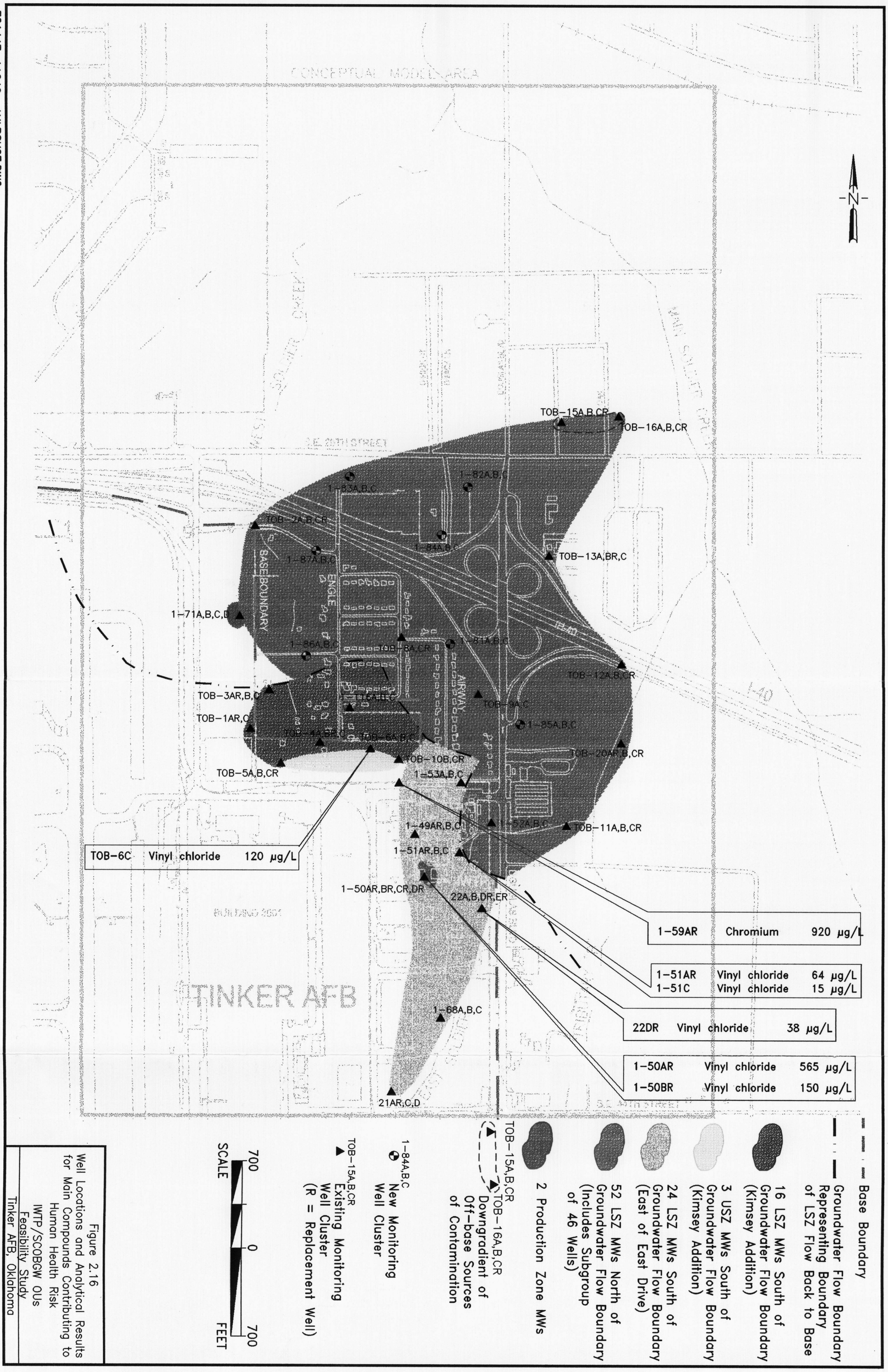

Figure 2.16
Well Locations and Analytical Results for Main Compounds Contributing to Human Health Risk
IMTP/SCOBGW OUs
Feasibility Study
Tinker AFB, Oklahoma

the unacceptable risk or HI (as discussed on a chemical-specific basis, below) are shown in the figure. For example, the figure does not show concentrations for barium, since barium was detected in all wells over a wide range of concentrations and because it is a naturally occurring element in the area. In addition, the IWTP/SCOBGW OUs RI report (Parsons ES, 1998) provides contour maps for the concentrations of contaminants of concern in the area.

The low detection frequency of the main compounds contributing to risk, and/or the occurrence of the compounds at concentrations contributing to risk (e.g., in a specific well, at adjacent wells, or at wells within the same well cluster) indicates that the potential risk due to groundwater contamination is not widespread in the IWTP/SCOBGW OUs area. The frequency of detection of contaminants was highest in the group of twenty-four LSZ wells east of East Drive. This area is representative of LSZ groundwater near the IWTP site.

2.8.1.1 Vinyl Chloride

Vinyl chloride contributed to unacceptable estimates of risk in two of the well groups. These estimates of unacceptable risk were due to the ingestion of groundwater as drinking water pathway. The chemical was found to individually exceed the EPA acceptable upper-bound target cancer risk range in the group of sixteen wells and the group of twenty-four wells.

Detections of vinyl chloride were at relative high concentrations, and the wells were all clustered in close proximity to the IWTP. Out of the sixteen LSZ wells in the former Kimsey Addition, vinyl chloride was detected in one well (TOB-6C) at a concentration of 120 micrograms per liter (μg/L). In the group of twenty-four LSZ wells east of East Drive, the chemical was detected in five wells (22DR, 1-51AR, 1-51C, 1-50BR, and 1-50AR) at concentrations of 38, 64, 16, 150, and 610 μg/L, respectively. The 610 μg/L sample from 1-50AR was a duplicate. The one well, TOB-6C, in the former Kimsey Addition area was located immediately north of Building 3001 and the IWTP. The five wells east of East Drive were located at the IWTP. These wells are located in close proximity to one another, with four of the wells in two clusters (1-50BR and 1-50AR, and 1-51AR, and 1-51C). The 1-50 wells are screened in layers 3 and 5, and the 1-51 wells are screened in layers 5 and 7.

In the six wells where vinyl chloride was detected, concentrations exceeded the EPA MCL and the State of Oklahoma regulatory drinking water level (2 μg/L). In addition, vinyl chloride is an anaerobic degradation product of DCE, PCE, and TCE. *Cis*-1,2-DCE was also a contaminant which contributed to risk in the group of LSZ wells east of East

Drive. TCE and PCE were also detected in several of the wells, although these two chemicals were not significant in the contribution to risk. Historical contaminants associated with the WWTF, in operation since 1943, have included vinyl chloride, DCE, PCE, TCE, and chromium.

2.8.1.2 *cis*-1,2-DCE

The EPA MCL and Oklahoma water quality level for *cis*-1,2-DCE is 70 µg/L. Due to the concentrations and high detection frequency of *cis*-1,2-DCE in LSZ wells, this chemical is of concern throughout the area. All wells, except three, however, had concentrations of *cis*-1,2-DCE below the 70 µg/L water quality level. These wells are located in the area east of East Drive (wells 1-50BR, 1-50AR, and 1-51AR). The *cis*-1,2-DCE contamination appears to be associated with past activities at the IWTP.

2.8.1.3 Trichloroethene

Although TCE was not identified as a contaminant contributing to human health risk, high concentrations were detected in some of the wells which contained other risk-contributing contaminants. In the group of twenty-four wells east of East Drive, TCE concentrations range from nondetected to 380 µg/L (layer 5, well 1-50AR). TCE was detected in fifteen of the twenty four wells. In the group of sixteen wells south of the flow boundary (former Kimsey Addition), TCE was only detected in four wells at concentrations ranging from 1.1 to 26 µg/L. The TCE concentration in two layer 7 wells (1-81 and TOB-8) north of the risk assessment groundwater flow boundary exceeded the MCL (53 µg/L and 11 µg/L, respectively vs. 5 µg/L). However, the actual layer 7 flow divide is located north of these wells, i.e., monitoring wells 1-81 and TOB-8 are upgradient from IWTP and Building 3001.

2.8.1.4 1,2-Dichloroethane

1,2-Dichloroethane was determined to contribute the highest risk of noncancerous health hazard in the fifty two well groups north of the groundwater divide. However, when the six wells are eliminated from the group due to offbase sources, 1,2-dichloroethane drops out as a main contributor to either cancerous or noncancerous risk. 1,2-Dichloroethane has been discovered in investigations of releases from gas stations in the area. In addition, no contaminant plume connects the wells with Tinker AFB. Furthermore, Soldier Creek does not discharge to the aquifer in this area. 1,2-Dichloroethane was detected at 96 µg/L in well TOB-15B, but did not exceed 1.4 µg/L in all of the other wells north of the groundwater divide. 1,2-Dichloroethane did not contribute to risk south of the divide.

2.8.1.5 Aldrin

Although aldrin was not identified in the sixteen LSZ well group or the twenty-four LSZ well group, it was determined to be the main cancerous risk factor in the forty-six well subset of the fifty-two LSZ wells north of the groundwater divide. The risk due to aldrin was greater than 1E-06, but not considered unacceptable (i.e., risk was less than 1E-04). Out of the twenty-four samples which were analyzed for pesticides, aldrin was detected in two wells at levels of 0.006 μg/L and 0.01 μg/L. The main exposure pathway was due to ingestion of the chemical in groundwater.

2.8.1.6 Background Metals

Nickel was the source of the highest noncancer health hazard in the sixteen LSZ wells due to the ingestion of contaminated groundwater. Although unacceptable risk was not exceeded, nickel did exceed the EPA MCL in one out of sixteen, three out of twenty-four, and three out of fifty-two LSZ wells. The average nickel concentration in all three well groups exceeded the background level for nickel in LSZ wells at Tinker AFB.

Thallium also contributed to an unacceptable RME cancer risk estimate for residents in the group of fifty-two wells due to the groundwater ingestion pathway. The compound was analyzed for in fewer wells (twelve wells), and detected in two of the wells (1-84A and 1-83C) at concentrations of 2.4 and 5 μg/L, respectively. The EPA MCL for thallium is 2 μg/L. Background data show that thallium was not detected in Del City or Midwest City wells, and it was not requested to be analyzed for in the groundwater investigation for the Central Oklahoma aquifer. The two wells where thallium was detected in this well group were in close proximity to each other; however, it was not extensively analyzed for in the area. Thallium is not a material used or disposed by Tinker AFB. No contaminant plume links Tinker AFB to these wells. In addition, thallium was only a trace element, not a contaminant of concern identified at the IWTP, and it was not identified as a contaminant of concern for the Building 3001/Soldier Creek NPL site. Based on the hydrogeological and historical data, the compound has not been detected in other investigations for Tinker AFB. Therefore, the potential risk estimate for thallium for the off-base well group area is not considered to be due to Tinker AFB activities. The off-base source of thallium contamination was not determined. Based on the evidence that thallium concentrations are not due to past or present base activities, the remediation of thallium is not an objective of the feasibility study.

2.8.2 Exposure Pathways

Results of the human health risk assessment show that ingestion of groundwater as drinking water is the exposure pathway which consistently contributes most to the unacceptable estimates of risk. Although the four exposure scenarios evaluated in the human health risk assessment were determined to be possible, the probability of occurrence is expected to be low. It is unlikely that a water well for drinking or other domestic purposes would have been placed in the USZ or LSZ. A record search of the city utility department in 1995 indicated all the residents in the Kimsey Addition are on city water except well 49. Well 49 is on the south of SE 29th Street and east of Engleside Avenue, about 2,500 feet north of the IWTP fence (see Figure 5.1 of the RI report). The address of well 49 is not on Oklahoma City or Midwest City Water Department's lists. Only seventeen domestic wells in the area remain open (one was approved by the county health department) and eight more have unknown status (one well is upgradient and two are on Tinker AFB property). These wells may be used for lawn irrigation or just on a standby basis.

USZ well (TOB-5B) in the former Kimsey Addition is are downgradient from contaminated groundwater at the north end of Building 3001, thus there is potential for contaminants from Building 3001 to have moved through this area. LSZ wells also represent an area where potential contamination may have resulted from leakage of USZ water (along margin) into the LSZ (i.e., the USZ is a possible source for water leaking into the LSZ along USZ margin). Only four contaminants (chloromethane, nickel, selenium, and silver) were found in USZ groundwater in this area, however, and not found to result in an unacceptable cancer risk or other adverse health effects.

Groundwater flows in the LSZ from the Kimsey Addition area, both to the north (to some degree) and downward, then back toward the base in response to the Building 3001 extraction system and hydrostratigraphy. Northward flow would be influenced by the groundwater flow divides, thus most groundwater is expected to move back toward the extraction system. Leakage of USZ water into the LSZ is also pulled back into the extraction system. Neither the LSZ nor the USZ in this area interacts with Soldier Creek or its tributaries.

The LSZ east of East Drive is vertically downgradient from East Soldier Creek and thus may be potentially influenced by water loss from the creek. There is also the concern for possible groundwater flow through the area from the IWTP. Contaminants associated with the IWTP site (including vinyl chloride and DCE in groundwater) were also contaminants of concern in the human health risk assessment. Layers of the LSZ groundwater may move northward from the IWTP, but would be limited by the groundwater flow divides of the next layer underneath, if the groundwater sinks, rather than moving off-base to the north. Flow in a large portion of this area is back toward the base in response to the Building 3001 extraction system and hydrostratigraphy.

2.9 SUMMARY OF OPTIMIZATION OF BUILDING 3001 GROUNDWATER EXTRACTION SYSTEM

Following the Building 3001 ROD, Tinker AFB installed a groundwater pump-and-treat (P&T) system to remediate the solvent and metal contamination. Figure 2.17 is the well field configuration. The groundwater treatment plant (GWTP) has a designed capacity of 210 gpm. The treated groundwater is reused in the industrial operations of Tinker AFB. The entire system was on line in June 1994. Currently the GWTP is processing 150 gpm.

An optimization study (Parsons ES, 1998) was performed to assess the effectiveness of extraction system and possible reconfiguration of the well field and pumping scheme to improve its efficiency. The data used spanned from March 1994 to October 1995. The simulation was performed using MODFLOW coupling with RWLK3D. Results of this study are:

(1) Figures 2.18 to 2.21 illustrate the 50-year capture zone and the containment zone. The 50-year capture zone represents the total area that will contribute water to the extraction system of Figure 2.17 over a 50-year time period. The containment zone represents the total area that is hydraulically controlled by the extraction system. Groundwater and contamination occurring beyond the 50-year capture zone but within the containment zone will reach the well field beyond 50 years.

(2) It is estimated that between 254 to 385 gallons of TCE was removed from the groundwater between September 1994 and November 1995. The average drawdown underneath Building 3001 was about 2 to 5 feet, and dewatering of the USZ, i.e., layer 1, occurred between March 1994 and September 1994.

(3) Out of the six pumping schemes for the Building 3001 groundwater operable unit,, the study elected Scenario 6 which was the adding of one extraction well at MW1-70B, the pulse pumping of the P-series wells, and the reduction of the flow rate in the R-series wells. The total pumping rate would be 90 gpm while maintaining the hydraulic containment of the plume. This is a proposed reduction of 60 gpm from the current 150 gpm throughput.

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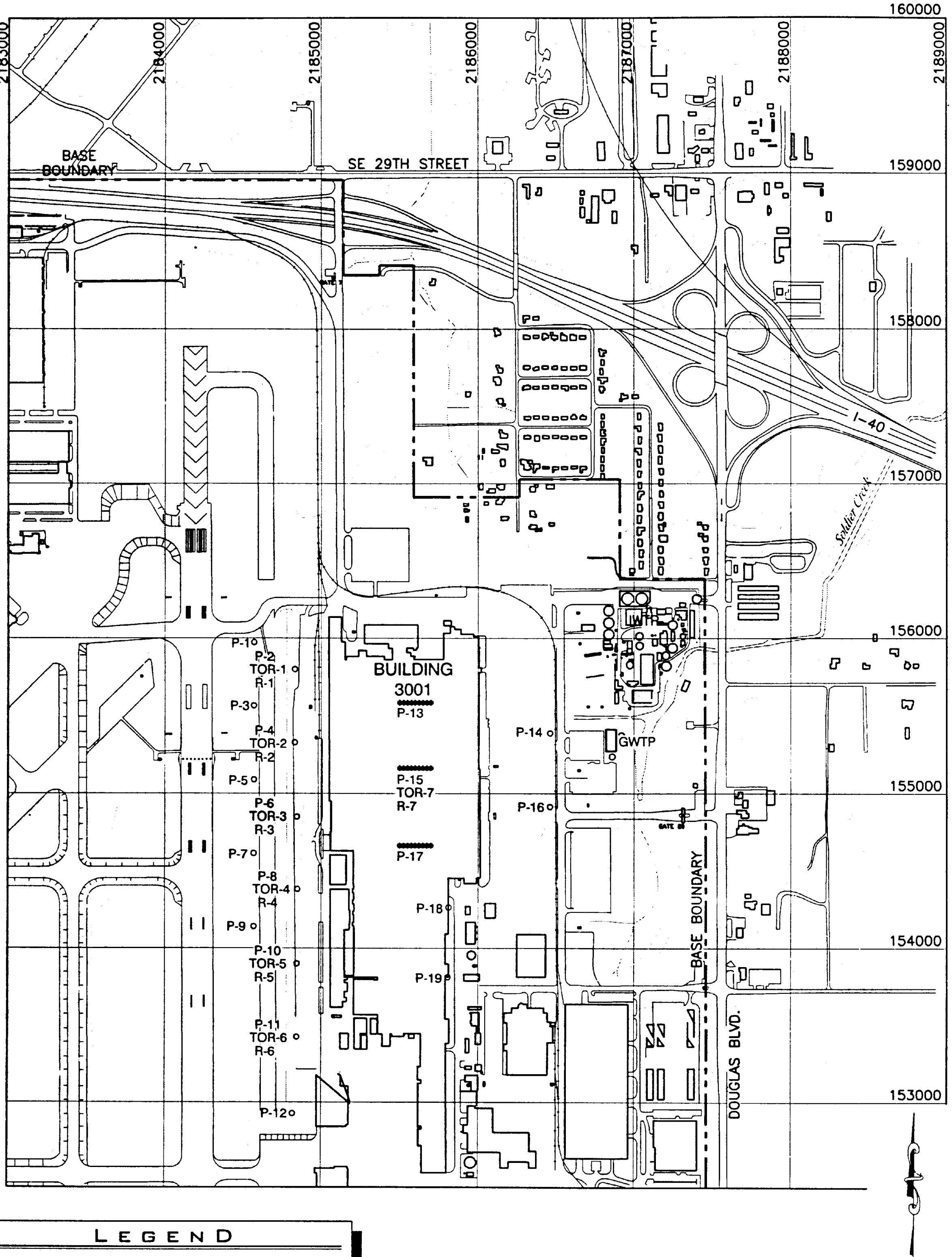

LEGEND

	Topographic Contour Line Contour Interval: 10 Feet
	Perennial Stream
	Intermittent Stream
P-13	Horizontal Extraction Well
P-9 o	Vertical Extraction Well

PROJECTION INFORMATION:
OKLAHOMA STATE PLANE COORDINATE
SYSTEM NORTH ZONE 3501

Figure 2-17

Building 3001
Groundwater Extraction Wells

Northeast Quadrant
Tinker AFB, Oklahoma

735762-03000 TKTP-EXWL1.DWG

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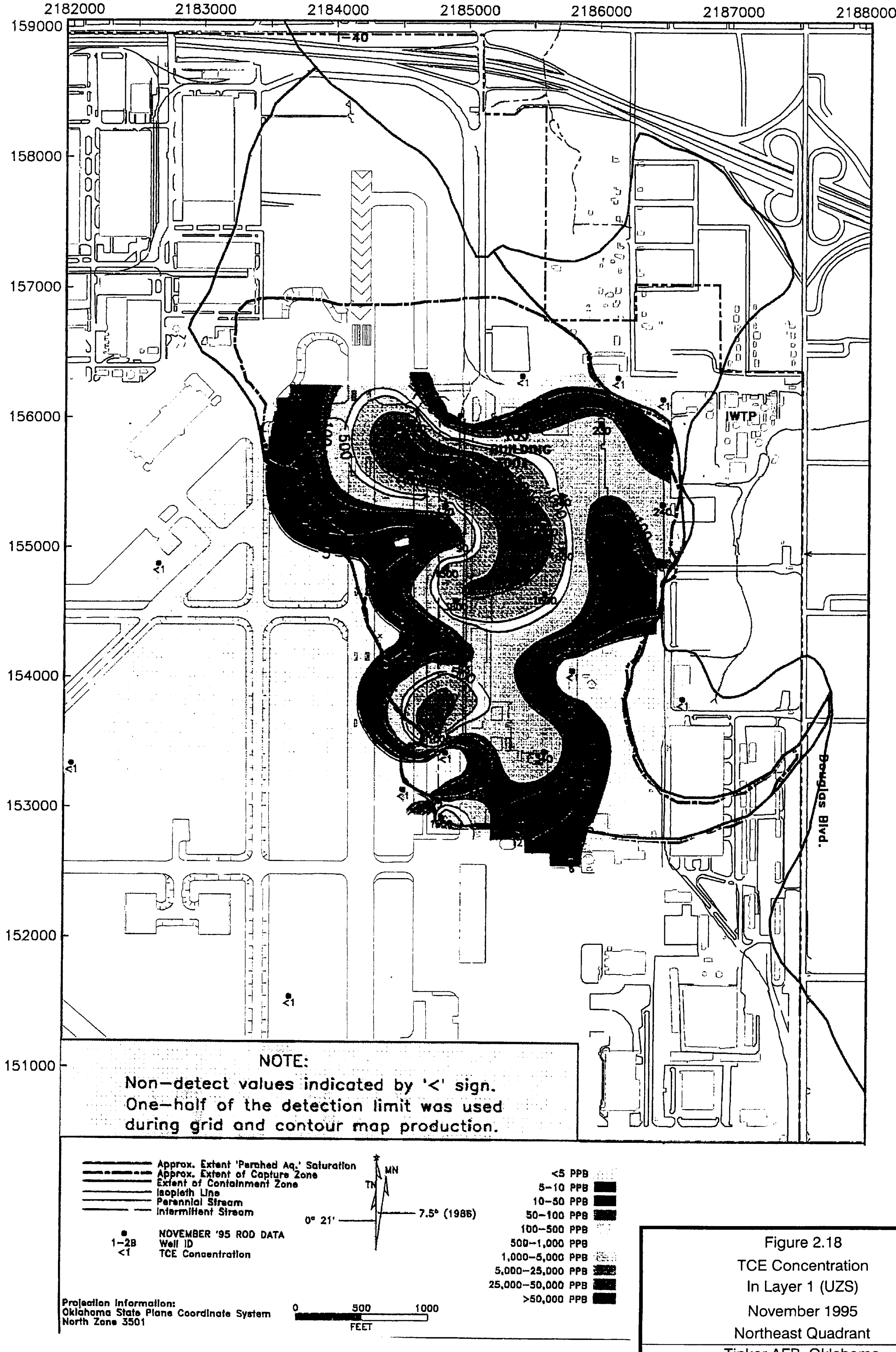

Figure 2.18
TCE Concentration
In Layer 1 (UZS)
November 1995
Northeast Quadrant
Tinker AFB, Oklahoma

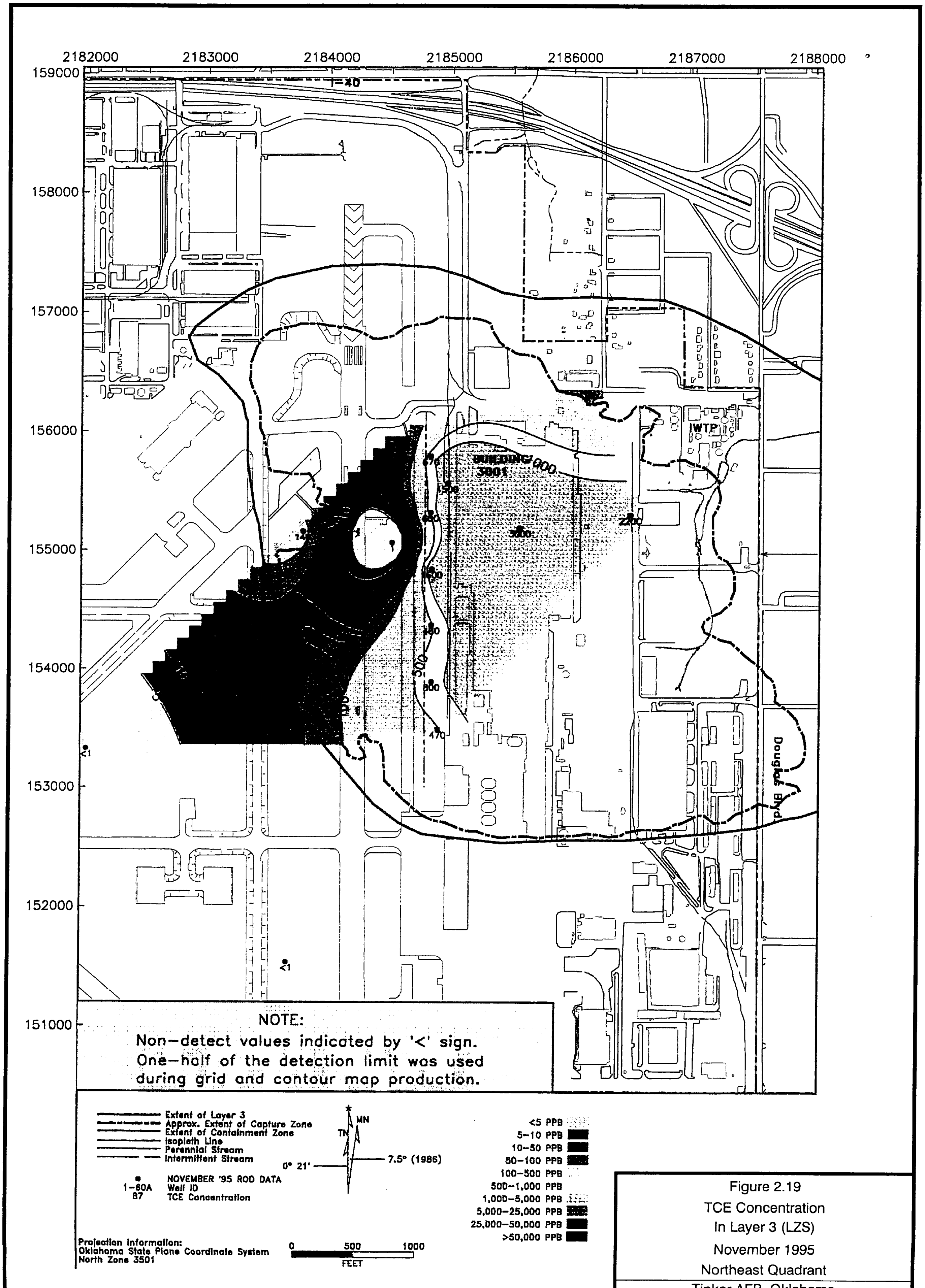

Figure 2.19
TCE Concentration
In Layer 3 (LZS)
November 1995
Northeast Quadrant
Tinker AFB, Oklahoma

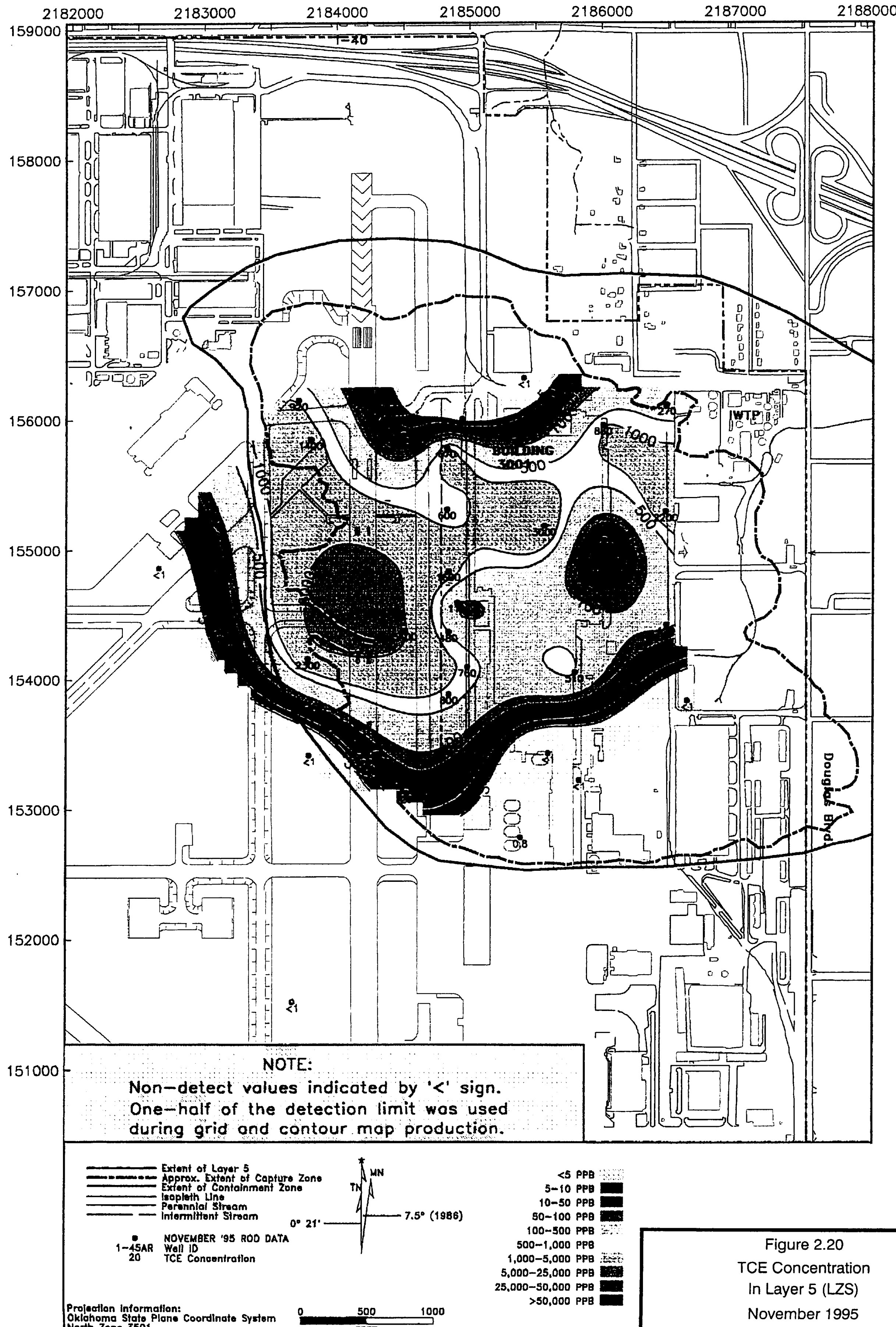

Figure 2.20
TCE Concentration
In Layer 5 (LZS)
November 1995
Northeast Quadrant
Tinker AFB, Oklahoma

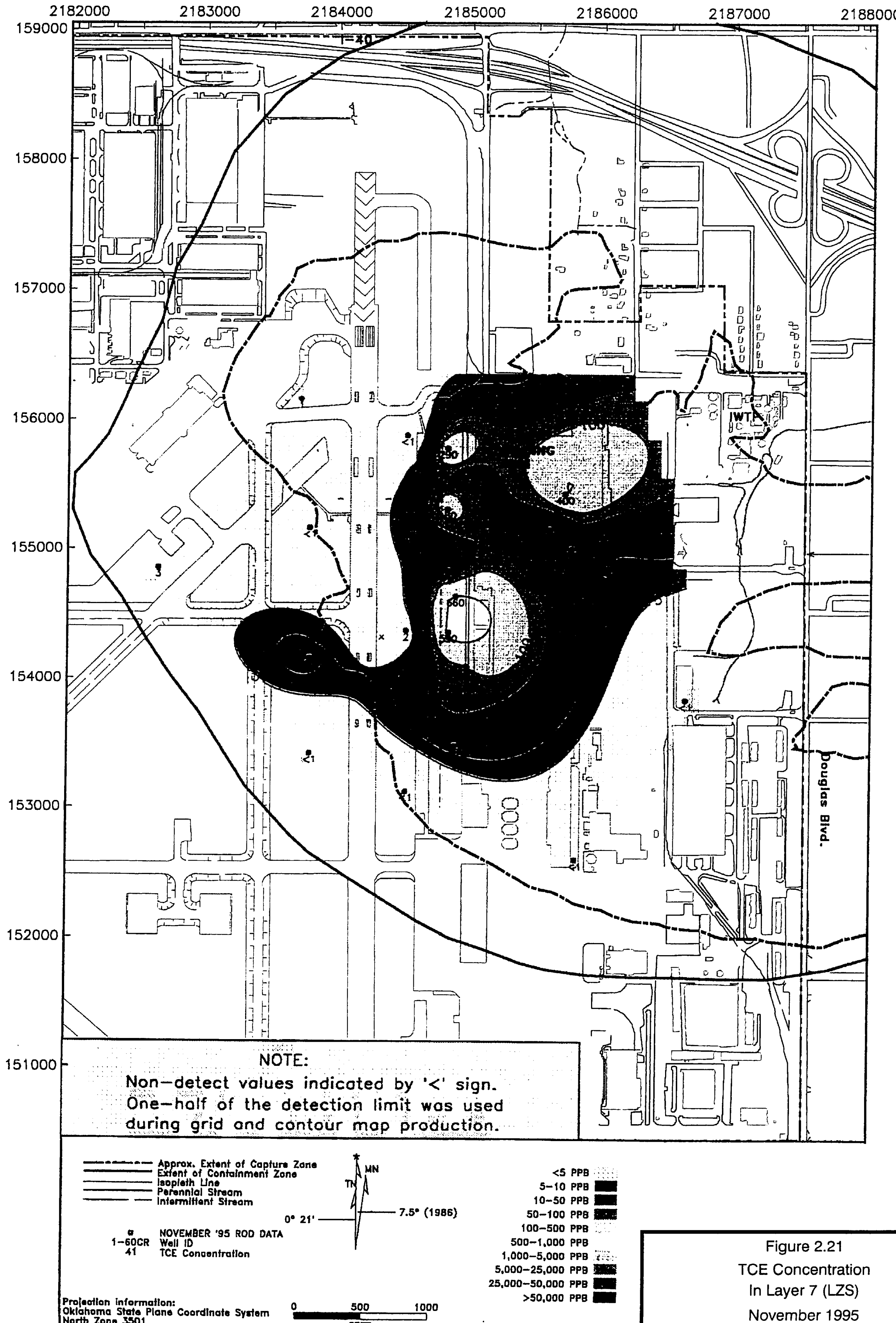

Figure 2.21
TCE Concentration
In Layer 7 (LZS)
November 1995
Northeast Quadrant
Tinker AFB, Oklahoma

SECTION 3

REMEDIAL ACTION OBJECTIVES

The first step in the FS process involves developing RAOs that address contaminants and media of concern, potential exposure pathways, and PRGs (EPA, 1988c). For human healt, the RAO is to prevent ingestion of groundwater having (1) carcinogens in excess of MCLs and a cancer risk of greater than 10^{-4} and, (2) noncarcinogens in excess of MCLs or reference dose. For environmental protection the RAO is to restore the groundwater aquifer (ibid., p.4-10) to PRGs. "RAOs for protecting human receptors should express both a contaminant level and an exposure route, rather than contaminant levels alone, because protectiveness may be achieved by reducing exposure (such as capping an area, limiting access, or providing an alternate water supply) as well as by reducing contaminant levels. Because RAOs for protecting environmental receptors typically seek to preserve or restore a resource (such as groundwater), environmental objectives should be expressed in terms of the medium of interest and target cleanup levels, whenever possible (ibid., p. 4-7 and 4-5)." The PRGs are initially based on readily available chemical-specific applicable or relevant and appropriate requirements (ARARs), such as MCLs. At the conclusion of the baseline risk assessment, PRGs are refined or confirmed and are based both on site-specific risk and chemical-specific ARARs.

PRGs that are modified based on the results of the baseline risk assessment must still meet the "threshold criteria" of: (1) protection of human health and the environment, and (2) compliance with ARARs. However, the NCP also allows for modification of PRGs during final remedy selection based on balancing criteria and factors relating to uncertainties, exposure, and technical feasibility. Final remediation goals (FRGs) are not determined until the site remedy is ready to be selected.

Identification of PRGs includes the determination of media and contaminants of potential concern, review of ARARs, evaluation of appropriate exposure pathways, and in some cases, final modification. Each of these steps is described in this section.

3.1 MEDIA AND CONTAMINANTS OF CONCERN

Results of the baseline risk assessment and review of ARARs have been used to determine the need for remedial action for groundwater contamination and to support decisions regarding remedial alternatives to address potential risks. The primary goals of remedial action at Tinker AFB are to minimize the potential for contamination migration, to protect human health from ingesting groundwater exceeding MCLs, and to protect the environment by restoring the aquifer to PRGs.

The baseline human health and ecological risk assessment examined potentially complete groundwater exposure pathways and resultant potential risk in the absence of remedial action (Parsons ES, 2000). The four human exposure scenarios identified as potentially complete included: (1) ingestion of contaminants in groundwater used as drinking water; (2) dermal contact with contaminants in groundwater while showering; (3) inhalation of volatile organics from groundwater while showering; and/or (4) uptake of contaminants through ingestion of homegrown fruits and vegetables following irrigation with groundwater. The potential human receptors were identified as current and future residents (for the four pathways) and base workers (for direct ingestion of groundwater). The two ecological exposure pathways determined to be potentially complete were: (1) ingestion of chemicals in groundwater by domestic animals and urban wildlife, and (2) vegetation exposure to contaminants via watering of lawns and gardens.

Groundwater monitoring wells were grouped separately for quantification of risk for each potential exposure scenario. The rationale for selection of wells and delineation of well groups for risk analysis were discussed in the baseline risk assessment report (Parsons ES, 2000). The general basis for well grouping consisted of several hydrogeological and groundwater use features, including separation of wells based on: (1) the primary groundwater zone (USZ, LSZ, or PZ); (2) the presence of the LSZ groundwater flow divides; (3) groundwater flow patterns (e.g., groundwater movement into an area from different potential sources of contamination, and groundwater movement from an area resulting in different potential impacts); (4) potential sources of contamination (on base and off base); and (5) current and potential future use characteristics of the groundwater. The predominant groundwater flow pathways and potential for contaminant migration are largely affected by the locations of the LSZ groundwater flow divides. The southern extent of the divides represents the predominant boundary of LSZ flow back towards the base. This boundary is referred to as the "groundwater flow boundary," as shown in Figure 2.15, and closely follows the northeastern boundary of the base, from slightly south to slightly north of the base boundary. In general, groundwater south of the divides flows to the south-southwest (back toward the base); groundwater north of the divides flows to the north.

Based on the well selection analysis, ninety-seven wells were delineated into five well groups for the baseline risk assessment. In addition, one of the well groups was evaluated as a subgroup of wells based on evidence of contamination due to off-base sources. Three well groups were delineated for the area south of the groundwater flow boundary: (1) sixteen LSZ wells in the Kimsey Addition; (2) three USZ wells in the former Kimsey Addition; and (3) twenty-four LSZ wells in the area east of East Drive. One well group was delineated for the area north of the groundwater flow boundary, consisting of fifty-two LSZ wells. This well group was also evaluated as a subgroup of forty-six wells based on the evidence of off-base sources of contamination at six wells located approximately 0.5 mile from the northeast boundary of the base. All but three of the wells north of the groundwater flow boundary were off-base wells. USZ groundwater north of the groundwater flow boundary was not included in the risk assessment because it is either not present in the area or, if present, is not hydraulically connected to the base. The fifth well group included two PZ monitoring wells.

The overall results of the IWTP/SCOBGW OUs baseline human health and ecological risk assessment showed that six on-base LSZ monitoring wells in the area south of the groundwater flow boundary had concentrations of vinyl chloride resulting in and contributing to estimates of cancer risk above the acceptable EPA (1990) health protective risk range (1E-04 to 1E-06). The unacceptable cancer risk estimates were for both the residential and base worker receptors. Five of the wells were located in the area east of East Drive, and one well was located in the former Kimsey Addition well group. These six LSZ wells are all within an area influenced by the IWTP site. No other unacceptable cancer risk or noncancer health hazard was estimated due to past or present activities at Tinker AFB for any of the well groups (including the well group area north of the groundwater flow boundary). There were also no estimated adverse effects on ecological receptors for any of the well groups.

Vinyl chloride was the only primary contaminant resulting in and contributing to the unacceptable cancer risk estimates. This contaminant was detected in only six of the ninety-seven wells evaluated in the risk assessment. The unacceptable risk estimates were primarily due to ingestion of groundwater as drinking water. In the area east of East Drive, the other three potential exposure pathways also contributed to the estimated cancer risk, although the pathway-specific risks were within the acceptable risk range.

Although the exposure pathways and scenarios were determined to be possible, the probability of current and future use of USZ and LSZ groundwater is expected to be very low. First, it is unlikely that a future private well would be placed in either the USZ or LSZ because alternate sources of water are available from surrounding municipal and base water supplies. Water for these supplies is taken from the PZ or surface water sources. Second, exposure to USZ and LSZ water would be limited since the majority of residences in the area have converted to city water. Third, USZ groundwater is not considered to be a good source of water due to the low yield and high naturally occurring chloride and sulfate levels. Fourth, exposure to USZ groundwater would be limited because private wells, although the majority have been closed, primarily withdraw water from the upper elevations of the LSZ. Furthermore, USZ groundwater north of the groundwater flow boundary, if present, is not hydraulically connected to the base, and the base does not use either USZ or LSZ groundwater. The six LSZ wells where vinyl chloride was detected are located on base and there is very low potential for off-base migration of contamination.

3.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS

As described above, all PRGs must, at a minimum, comply with ARARs. "Applicable" requirements are the standards promulgated under federal or state law specifically addressing hazardous substances, remedial action, locations, or other circumstances at a CERCLA site sufficiently similar to those encountered at the CERCLA site where their use is suited. "Relevant and appropriate" requirements are those cleanup standards promulgated under federal or state law that, while not "applicable" to a hazardous substance, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the particular site. The determination that a requirement is relevant and appropriate is a two-part process. The requirement must first be found to be relevant, then it must be found to be appropriate. During the FS process and in the development of remedial alternatives, relevant and appropriate requirements are accorded the same weight and consideration as applicable requirements.

"To be considered" (TBC) requirements include requirements and non-promulgated documents to be considered in the process of developing and screening remedial alternatives. The TBC category includes federal and state non-regulatory requirements such as guidance documents, advisories, or criteria. Non-promulgated advisories or guidance documents do not have the status of ARARs. However, if no specific ARARs for a contaminant or situation exist, or if existing ARARs are not sufficiently protective, guidance or advisories would be identified and used to ensure that a remedy is protective.

For the purposes of this analysis, ARARs have been grouped into three categories:

1. Contaminant-specific. Health- or risk-based numerical values or methodologies which result in the establishment of numerical values. These values establish the acceptable amount or concentration of chemical that may be found in, or discharged to, the ambient environment.
2. Location-specific. Restrictions placed on the concentration of contaminants or on the conduct of activities only because they occur in special locations.

3. Action-specific. Technology- or activity-based requirements or limitations on actions taken with respect to hazardous wastes.

CERCLA identifies certain circumstances under which an otherwise applicable or relevant and appropriate requirement may be waived. Consideration of these waivers for state Superfund sites also appears to be appropriate. The waivers apply only to meeting ARARs with respect to remedial actions onsite, and do not apply to the statutory baseline requirements (i.e., protective of human health and the environment, cost effective, and use of permanent solutions). The waivers include:

- Interim Measure - The remedial action selected would be only part of a total remedial action that will comply with ARARs when completed.
- Greater Risk to Human Health and the Environment - Compliance with the ARAR would result in greater risk to human health and the environment than alternative options.
- Technical Impracticability - Compliance with the ARAR would be technically impracticable from an engineering standpoint.
- Equivalent Standard of Performance - The remedial action selected would attain a standard of performance equivalent to that required under the otherwise applicable standard, requirement, criterion, or limitation, through use of another method or approach.
- Inconsistent Application of State Requirements - With respect to a state standard, requirement, criterion, or limitation, the state has not consistently applied (or demonstrated the intention to apply consistently) the standard, requirement, criterion, or limitation in similar circumstances for other remedial actions.

In addition to the waivers noted above, CERCLA 121(e) exempts any on-site response action from obtaining permits. Though the action must still comply with the substantive requirements of applicable permits, the administrative requirements of any federal or state permitting agency should not need to be addressed. Off-site actions must comply with all administrative and substantive requirements.

The following five steps are taken in the identification and analysis of ARARs:

1. Identify all potential chemical-, location-, and action-specific ARARs. These three classifications are defined and discussed below.
2. Analyze the potential ARARs to determine whether they are applicable to the individual site conditions.

3. If the requirements are not applicable to the site conditions, analyze them to determine if they are relevant and appropriate.

4. Evaluate other criteria when ARARs do not exist or when risk assessment indicates that existing ARARs are not sufficient to protect human health and the environment.

5. Determine if a waiver from the ARARs is appropriate.

This section identifies chemical-specific, location-specific, and action-specific ARARs which may be applicable to the remedial action.

3.2.1 Contaminant-specific ARARs

3.2.1.1 Air Quality

The ARARs for air quality listed below apply if contaminants will be released into the atmosphere during construction or treatment.

- 42 USC 7401-7642 et seq. (applicable): Clean Air Act (CAA) and amendments. Regulates emissions to protect human health and the environment. Enabling statute for major provisions such as National Ambient Air Quality Standards (NAAQS), National Emission Standards for Hazardous Air Pollutants (NESHAP), and New Source Performance Standard (NSPS). Applicable for remedial alternatives that may result in air emissions.

- 40 CFR part 50 (applicable): National primary and secondary ambient air quality standards (NAAQS). Establishes national ambient air quality standards for the protection of public health and welfare. Standards are applicable to any alternative emitting regulated pollutants.

- 40 CFR part 61 (applicable): National emission standards for hazardous air pollutants (NESHAP). Requires minimization of emissions, specifies emissions tests and monitoring requirements, and sets limits on several hazardous air pollutants.

- 40 CFR part 58 (applicable): Ambient air quality surveillance. Defines quality assurance, monitoring methods, instrument siting, and operating schedule for ambient air quality surveillance.

- 40 CFR part 52 (applicable): Approval and promulgation of implementation plans. Defines general provisions for the contents of state implementation plans (SIPs). This section also incorporates by reference the Oklahoma SIP, including provisions relating to designation of attainment areas and specific pollutant control strategies.

Over 250 stationary air emission sources at Tinker AFB operate in a "low requirements" regulatory structure that is afforded by Oklahoma County's status of attainment of current NAAQS. Most of these sources are "grandfathered," and the compliance requirements are satisfied by providing an annual emissions summary to the Oklahoma Department of Environmental Quality (ODEQ). Sources that are added to the Tinker AFB inventory of air pollution units since promulgation of permitting regulations are required to be subjected to ODEQ scrutiny via "Permit to Construct" application submittals. However, exemptions described in Oklahoma Administrative Code (OAC) 252:100-41-43(5) for *de minimus* emissions will likely apply to any remediation alternative considered. These exemptions allow emission of 1,200 pounds per year of "highly toxic" substances (not to exceed 0.57 pounds per hour).

3.2.1.2 Water Quality

The following apply to the discharge of water to surface water.

- 33 USC 1251-1376 (applicable): Clean Water Act (CWA). Provides for the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters. Enabling statute for a system of minimum national effluent discharge standards, a construction grant program for public-owned treatment works (POTWs), ocean discharge requirements, and water quality criteria.
- 40 CFR part 131 (applicable): Water quality standards. Implements section 101 of the CWA, which specifies the national goals of eliminating the discharge of pollutants, prohibiting the discharge of toxic pollutants in toxic amounts, and implementing programs for control of nonpoint sources.
- 40 CFR part 131.12 (applicable): Antidegradation policy. Establishes standards to prevent a body of water which has an existing high standard from degrading to a lower standard.

The following ARARs are applicable only to public water supply systems. However, they are often considered to be relevant and appropriate to groundwater that may be used as a drinking water source.

- 42 USC 300f et seq., Pub. L. 93-523 (relevant and appropriate): Safe Drinking Water Act (SDWA). The goal of the SDWA is to protect human health by protecting the quality of drinking water. The SDWA authorizes the establishment of drinking water standards. Applies to CERCLA site discharges to public drinking water sources, including underground drinking water sources.
- 40 CFR part 141 (relevant and appropriate): Establishes health-based standards for public water systems known as maximum contaminant levels (MCLs). MCLs

are applicable at the tap when the water is directly provided to twenty-five or more people or fifteen or more service connections. Otherwise, MCLs are relevant and appropriate.

- 40 CFR part 141.11 (relevant and appropriate): Maximum inorganic chemical contaminant levels for public water supply systems. This section establishes MCLs for inorganic chemicals.
- 40 CFR part 141.12 (relevant and appropriate): Maximum organic chemical contaminant levels for public water supply systems. This section establishes MCLs for organic chemicals.
- 40 CFR 141, Subpart F (relevant and appropriate): Maximum contaminant level goals (MCLGs). Establishes drinking water quality goals set at levels of no known or anticipated adverse health effects, with an adequate margin of safety. MCLGs are not federally enforceable drinking water standards, but CERCLA 121(d) has raised MCLGs and water quality criteria to the level of potentially relevant and appropriate. MCLGs may be considered when a CERCLA cleanup may require more stringent standards than the MCLs. EPA has determined that the use of MCLGs will be decided on a case-by-case basis. MCLGs are relevant and appropriate where the chemical-specific goal is not zero. For carcinogens, by policy, EPA sets MCLGs at zero.
- 40 CFR part 403 (applicable/relevant and appropriate): National pretreatment standards. Sets standards to control pollutants which pass through or interface with treatment processes in POTWs or which may contaminate sewage sludge.
- 40 CFR part 264 subpart F (relevant and appropriate): Releases from solid waste management units. Standards for protection of groundwater are established under this citation. Certain parts of subpart F are directly applicable to Part B RCRA permitted sites and other parts are relevant and appropriate.

3.2.1.3 Waste Disposal

This ARAR is used when wastes are disposed of off site.

- 40 CFR part 268 (relevant and appropriate): Land disposal restrictions (LDRs). Restricts the disposal of listed and characteristic hazardous waste which contain hazardous constituents exceeding designated levels. Specifies treatment standards that must be met before these wastes can be land disposed. Only applies when the waste is "placed" on the land.

3.2.2 Location-specific ARARs

3.2.2.1 Endangered Species

- 40 CFR part 257.3-2 (relevant and appropriate): Facilities or practices shall not cause or contribute to the taking of any endangered or threatened species.

3.2.2.2 Location Standards

- 40 CFR part 264.18 (relevant and appropriate): Location standards for hazardous waste facilities. The general requirements for locating a hazardous treatment, storage, or disposal facility are found in this section. They include provisions for seismic considerations and floodplains.
- 40 CFR part 241.202 (relevant and appropriate): Site selection for landfills shall be consistent with public health and welfare. It shall also be consistent with land-use plans and air and water quality standards.

3.2.2.3 Antiquities

- 16 USC part 469a-1 (applicable): The Archaeological and Historic Preservation Act requires that action be taken to recover and preserve artifacts.
- 36 CFR part 800 (relevant and appropriate): Action must be taken to preserve historic properties. Actions must be planned to minimize harm to national historic landmarks.

3.2.3 Action-specific ARARs

3.2.3.1 Solid Waste Management

- 40 part CFR 241.100 (relevant and appropriate): Guidelines for the land disposal of solid wastes. These regulations are geared specifically toward sanitary landfills. However, they are applicable to all forms of land disposal and land-based treatment.
- 40 CFR part 241.204 (applicable): Water quality. The location, design, construction, and operation of land disposal facilities shall protect water quality.
- 40 CFR part 241.205 (applicable): The design, construction, and operation of land disposal facilities shall conform to air quality and source control standards.
- 40 CFR part 257.3 (relevant and appropriate): Establishes criteria to assess the impact of disposal operations, including such considerations as floodplains, endangered species, air, surface water, groundwater, and land used for food-chain crops.

3.2.3.2 Hazardous Waste Management

- 40 CFR part 260 (may be applicable): Hazardous waste management systems - general. Provides definitions of hazardous waste terms, procedures for rule making petitions, and procedures for delisting a waste. May be applicable if variance or delisting is required.
- 40 CFR part 262 (applicable/relevant and appropriate): Standards applicable to generators of hazardous waste. Applicable if the selected alternative involves generation and off-site transport of hazardous wastes.
- 40 CFR part 262.11 (applicable): This regulation requires a person who generates a solid waste to determine if that waste is a hazardous waste.
- 40 CFR part 263 (applicable/relevant and appropriate): Standards applicable to transporters of hazardous waste. Establishes standards which apply to persons transporting hazardous waste within the U.S. or if the transportation requires a manifest under 40 CFR part 262. Applicable if the selected alternative involves off-site transport of hazardous wastes.
- 40 CFR part 264 (applicable): Establishes hazardous waste management facility standards and requirements. The on-site disposal areas used for stockpiling, mixing, and extended bioremediation of wastes must meet the substantive requirements of the 40 CFR subparts listed below. This regulation is applicable for hazardous wastes and is also relevant and appropriate for certain wastes which are not hazardous wastes.
  - Subpart B (general facility standards).
  - Subpart C (preparedness and prevention).
  - Subpart D (contingency plan and emergency procedures).
  - Subpart E (manifest system, record keeping, and reporting).
  - Subpart F (releases from solid waste management units). This subpart is applicable if hazardous waste remains on site. The maximum contaminant concentrations that can be released from hazardous waste units are the same as the MCLs.
  - Subpart G (closure and post closure). This subpart is applicable if hazardous waste is treated, stored, or disposed of in a new on-site unit. It does not apply for consolidation within the area of contamination or *in-situ* treatment.
  - Subpart H (financial requirements). Applicable for closure/post-closure of any treatment or disposal unit.

  - Subpart I (use and management of containers). Applicable if remedy involves storage of hazardous waste in containers.
  - Subpart J (tank systems). Applicable if remedy involves storage of hazardous waste in tank systems.
- 40 CFR part 270 subpart C (may be applicable): Establishes permit conditions, including monitoring, record-keeping requirements, operation and maintenance requirements, sampling and monitoring requirements. Although no permit is required for activities conducted entirely on site, the substantive requirements of these provisions may be applicable if Tinker AFB has a permit for hazardous waste storage.
- 40 CFR part 270 subpart B (relevant and appropriate): Defines the required contents of a hazardous waste management (HWM) permit application. The substantive requirements of these provisions are relevant and appropriate.
- 49 CFR part 107, 171-177 (applicable/relevant and appropriate): Hazardous materials transportation regulations. Applicable if waste is shipped off site.

3.2.4 Other Selected Applicable Laws

The only federal laws that are ARARs are environmental and facility siting laws. Nevertheless, all removal and remedial actions must fully comply with all other applicable laws. Cited below are only a few selected laws under the Occupational Safety and Health Act (OSHA) that may be applicable to the contemplated remedial actions; these are in no way intended to constitute an exhaustive list of the laws applicable to the remedial actions. The parties conducting the remedial action are responsible for identifying and complying with all applicable laws.

- 29 USC 651-678: Occupational Safety and Health Act. Regulates worker health and safety. Applies to all response activities at hazardous waste operations/sites.
- 29 CFR part 1910.50: Occupational noise. No worker shall be exposed to noise levels in excess of the levels specified in this regulation.
- 29 CFR part 1910.1000: Occupational air contaminants. The purpose of this rule is to establish maximum threshold limit values for air contaminants to which it is believed nearly all workers may be repeatedly exposed day after day without adverse health effects. No worker shall be exposed to air contaminant levels in excess of the threshold limit values listed in the regulation.
- 29 CFR part 1910.1200: Requires that each employer compile and maintain a workplace chemical list which contains the chemical name of each hazardous chemical in the workplace, cross-referenced to generally used common names.

This list must indicate the work area in which each such hazardous chemical is stored or used. Employees must be provided with information and training regarding the hazardous chemicals.

- 29 CFR part 120: Applies to employers and employees engaged in sites that have been designated for cleanup, and other work related to RCRA and CERCLA. The regulation establishes proceedings for site characterization and control, and requirements for employee training and medical monitoring.

3.2.5 Other Potential Criteria, Advisories, and Guidance to be Considered

- 40 CFR part 143: National secondary drinking water standards. Secondary maximum contaminant levels (SMCLs) are standards to control chemicals in drinking water that primarily affect the aesthetic qualities relating to public acceptance of drinking water. Secondary standards are not federally enforceable; they are intended as guidelines for the states. SMCLs are not ARARs unless promulgated by the state.
- EPA and National Academy of Sciences (NAS) health advisories. Health advisories (HAs) are developed for short-term, long-term, and lifetime exposures. The advisories are considered to be guidance and are not enforceable.
- 40 CFR part 264.500-264.560 subpart S: Corrective action for solid waste management at hazardous waste management facilities. Rule establishes procedures and technical requirements for implementing corrective action under Section 3004/(u) of RCRA. The regulations define requirements for conducting remedial investigations, evaluating potential remedies, and selecting and implementing remedies at RCRA facilities. Provisions of the proposed rule (e.g., media cleanup standards, conditional remedies, etc.) must be addressed as TBCs.
- 40 CFR part 264.552: Corrective action management units and temporary units; corrective action provisions. Provides for designation of temporary staging areas for treatment and subsequent redeposition of waste, such as waste piles (soils) without invoking the LDRs. Some aspects of this rule may be relevant if selected remedies involve redeposition of waste onsite.

3.3 DEVELOPMENT OF CONTAMINANT-SPECIFIC PRGs

In the IWTP/SCOBGW OUs baseline human health and ecological risk assessment, vinyl chloride was the only contaminant of potential concern resulting in and contributing to unacceptable estimates of risk (Parsons ES, 2000). The chemical was detected in only six of the ninety-seven wells evaluated in the risk assessment, but at concentrations which resulted in cancer risk estimates above the acceptable EPA (1990) health protective risk range (1E-04 to 1E-06). The six LSZ wells where vinyl chloride was detected are located on base, within an area influenced by the IWTP site (five of the wells were located in the area east of East Drive and one well was located in the former Kimsey Addition). No other unacceptable cancer risk or noncancer health hazard were estimated due to past or present activities at Tinker AFB for any of the well groups (including the well group area north of the groundwater flow boundary). There were also no estimated adverse effects on ecological receptors for any of the well groups.

The unacceptable cancer risk estimates were for both the residential and base worker receptors, primarily due to direct ingestion of vinyl chloride tainted groundwater. Calculating the risk-based PRG involves identifying the most appropriate exposure pathways, exposure parameters, and equations. At the conclusion of Section 3, the risk-based PRG is compared to the chemical-specific ARAR to determine the appropriate target clean-up goal for vinyl chloride in groundwater.

3.3.1 Exposure Pathways and Parameters

As previously discussed, the potential exposure pathways as identified in the baseline risk assessment report include (1) direct ingestion of groundwater used as drinking water; (2) dermal contact with contaminants in groundwater while showering; (3) inhalation of volatile organics from groundwater while showering; and/or (4) uptake of contaminants through ingestion of homegrown fruits and vegetables following irrigation with groundwater. The two receptor populations identified for the potential groundwater exposure pathways were the resident and base worker. Under the land use scenario, residents were evaluated for each pathway, while base workers were considered to be exposed to groundwater via the ingestion pathway only. The baseline risk assessment report gives the rationale for pathway selection (Parsons ES, 2000).

EPA guidance was followed in the development of the risk-based PRG for vinyl chloride. Because the NCP (EPA, 1990a) encourages protection of groundwater to maximize its beneficial use, EPA guidance suggests that risk-based PRGs be based on residential exposures once groundwater is determined suitable for drinking, as it is in the vicinity of Tinker AFB. Therefore, residential receptor scenarios guide the development of the risk-based PRG for vinyl chloride. Also, to be consistent with the EPA basis for developing the risk-based PRG for residential exposure to potentially potable groundwater (groundwater that has been designated as usable for drinking water, and other domestic uses), direct ingestion of groundwater and inhalation of contaminants from groundwater are considered in the PRG calculation. In addition, the inhalation route of exposure is for daily inhalation exposure based on all uses of household water (which includes showering, as well as other uses such as washing clothes and dishes). As explained below, dermal absorption and uptake via ingestion of homegrown fruits and vegetables are viewed as highly tentative estimates of risk and therefore were not used in the calculation of the risk-based remediation level.

Currently, EPA and EPA Regions have adopted use of direct ingestion and inhalation routes of exposure to calculate the PRG for residential exposure to potentially potable groundwater (EPA, 1991b; 1996b; and 1996c). Dermal absorption and intake of contaminants due to ingestion of fruits and vegetables irrigated with contaminated groundwater are not specified in the guidance due to the uncertainties inherent in the process of estimating potential risk associated with these routes of exposure. For example, due to a lack of dermal toxicity studies for the vast majority of chemical substances, no toxicity values are currently available for the dermal route of exposure. These and other uncertainties specific to these routes of exposure are given in the baseline risk assessment report (Parsons ES, 2000). In general, estimates of the contributions of these two pathways to the overall risk needs to be viewed as highly tentative. In addition, because the unacceptable risk estimates for vinyl chloride were primarily due to direct ingestion of groundwater as drinking water, ingestion of groundwater is the most appropriate pathway for calculating the risk-based PRG. In the area east of East Drive, the other three potential exposure pathways also contributed to the estimated cancer risk, but the pathway-specific risks were within the acceptable risk range. Therefore, calculation of the vinyl chloride PRG based on residential ingestion and inhalation exposures results in a very conservative (health-protective) remediation level.

The restrictive scenario of the resident also provides a very conservative level of protection for all receptors potentially exposed to the contaminated groundwater. As discussed in the risk assessment report (Parsons ES, 2000), residential receptors have higher exposure and intake rates than base worker receptors, and thus the estimated risk for the resident would be higher than that of the base worker. The residential scenario is also conservative because the probability of current and future use of USZ and LSZ groundwater is very low. It is unlikely that a future private well would be placed in either the USZ or LSZ because alternate sources of water (PZ or surface water sources) are available from surrounding water supplies. Current exposure to USZ and LSZ water would also be limited since the majority of residences in the area have converted to city water. Also, the base does not use either USZ or LSZ groundwater. The six LSZ wells where vinyl chloride was detected are located on base and there is very low potential for off-base migration of contamination.

Residential Adult Exposure Scenario

Exposure to a contaminant (i.e., vinyl chloride) can be estimated in two ways: the reasonable maximum exposure (RME) and the average, or central tendency (CT) exposure. The RME is used to estimate risk for decision-making purposes. CT exposure-based results are for comparison only. The RME values for exposure and intake variables (e.g., intake rates, exposure frequency, exposure duration) are used in the development of the risk-based PRG.

The potential residential adult receptor is assumed to weigh 70 kilograms. Exposure to the contaminated groundwater is assumed to occur for 350 days a year (accounting for 15 days vacation a year using water from a different source) and for a 30-year duration (the national upper bound time that a resident lives in the same house). The resident is assumed to ingest 2 liters of contaminated site groundwater per day. The average daily inhalation rate is 15 cubic meters. These assumptions are standard default assumptions as described by the EPA (1989a; 1989b; 1991a; and 1993).

Vinyl chloride is a class A carcinogen with an oral slope factor (SF_o) of 1.90E+00 and an inhalation slope factor (SF_i) of 3E-01. These toxicity values were taken from the Health Effects Assessment Summary Tables (HEAST) (EPA, 1995a); no values are currently given in the Integrated Risk Information System (IRIS) on-line database (EPA, 1995b). There are no available toxicity values for noncarcinogenic effects of vinyl chloride. Thus, only a cancer-based PRG is calculated.

Intakes for carcinogens are averaged over the conventional human life span (70 years). This accounts for the fact that cancer is considered to be a nonthreshold phenomenon and that the risk of developing cancer is accrued over a lifetime of exposure. The risk assessment report contains more information concerning the calculations (Parsons ES, 2000).

The residential child receptor was not included in the baseline risk assessment or development of the risk-based PRG because the child resident is not a specific target receptor for groundwater exposure pathways (EPA, 1991a; 1993). EPA's supplemental risk assessment guidance (EPA, 1991a) and guidelines for assessing exposures (EPA, 1993) only specify age-adjusted intake (i.e., child versus adult) for incidental ingestion of soil and dust, not for ingestion of potable water. Additionally, exposure and intake values used to estimate potential risk are limited for the child receptor as compared to the adult receptor, especially for the groundwater exposure pathways. Thus, any use of groundwater exposure variables for children (standard default values, if available, or values based on best professional judgment) would likely add additional uncertainties into the estimates of risk.

3.3.2 Risk-Based Calculations

Risk-based and ARAR-based PRGs for the IWTP/SCOBGW OUs at Tinker AFB are presented below. The EPA (1991b) guidance document, *Risk Assessment Guidance for Superfund: volume 1 - Human Health Evaluation Manual, part B*: "Development of Risk-Based Preliminary Remediation Goals" (OSWER Directive 9285.7-01B) was generally followed in development of the risk-based PRG for vinyl chloride. The assumptions, intake variables, and toxicity information presented in the baseline risk assessment report (Parsons ES, 2000) were also used in the development of the risk-based PRG.

The two general sources of chemical-specific RAOs are concentrations based on ARARs and concentrations based on risk calculations (PRGs). ARARs include concentration limits set by environmental regulations. Potential ARARs for remedial actions at the IWTP/SCOBGW OUs are provided in Section 3.2. Risk-based calculations set concentration limits using carcinogenic and/or noncarcinogenic toxicity values under specific exposure conditions. As previously explained, carcinogenic toxicity values are used in the development of the vinyl chloride PRG.

PRGs are generally calculated using a baseline 1E-06 incremental risk for potential carcinogens. In addition to the baseline 1E-06 risk calculation, incremental risks of 1E-05 and 1E-04 are also calculated. Under the NCP (EPA (1990a), the target risk range for carcinogenic risk associated with a Superfund site is one in ten thousand (1E-04) to one in one million (1E-06). Risks are considered acceptable within or below this range and unacceptable if above 1E-04.

The standard EPA equation for calculation of the residential PRG for a carcinogenic chemical in groundwater is given below. The equation includes the terms for evaluating direct ingestion and inhalation of the contaminant:

$$PRG = \frac{TR \times BW \times AT \times 365 days/year}{EF \times ED\ [(SF_o \times IR_w) + (SF_i \times K \times IR_a \times CF)]}$$

Where:

Factor	Residential Adult
TR = Target excess lifetime cancer risk (unitless)	1E-04 to 1E-06
BW = Body weight (kg)	70
AT = Averaging time (yr)	70
SF_o = Oral slope factor $(mg/kg\text{-}day)^{-1}$	Chemical-specific
IR = Water ingestion rate (L/day)	2

Factor	Residential Adult
SF_i = Inhalation slope factor $(mg/kg\text{-}day)^{-1}$	Chemical-specific
K = Volatilization factor (unitless)	0.0005 (default)
CF = Conversion factor (L/m^3)	1000
IR_a = Daily indoor inhalation rate (m^3/day)	15
EF = Exposure frequency (days/yr)	350
ED = Exposure duration (yr)	30

3.4 ASSUMPTIONS IN THE ESTIMATES OF RISK

3.4.1 Exposure Assumptions and Uncertainties in the Quantification of Risk

Assumptions are an integral part of the development of a risk assessment. Identification of assumptions and subsequent uncertainties and their impact on estimated risks helps to place the risk estimates in proper perspective. High uncertainty (low confidence, low level of information) indicates that a value is less accurate and more likely to change, given more information. Low uncertainty (high confidence) is an indication that a value is more accurate and less likely to change as more data become available. A range of possible assumptions exists which can be used to represent any given uncertainty. Realistic assumptions are generally those about which a significant amount of information is available, or that have a low level of uncertainty.

The approach used in the development of the risk-based PRG, based upon residential adult exposure to vinyl chloride in groundwater, was to make exposure assumptions that were generally conservative to ensure that the remediation level is sufficiently low to be protective of human health and the environment. Assumptions were made in the baseline risk assessment during characterization of the level of contamination, initial selection of chemicals of concern, assignment of critical toxicity values, the exposure assessment, and in the risk characterization when exposures to multiple chemicals were summed. Because of a relatively high level of uncertainty, individual assumptions in the risk assessment were conservative. Collectively, the conservativeness of individual assumptions are at least compounded and may be multiplicative, and provides for a very conservative risk assessment overall. The major exposure assumptions and uncertainties are presented below with discussion of the impact of the uncertainty and conservativeness of the assumptions on the PRGs.

The following assumptions directly affect the estimation of exposures and the resulting calculated PRG. Because of the uncertainty associated with potential exposures at the IWTP/SCOBGW OUs, these conservative assumptions were selected. When many conservative assumptions are used to develop a risk-based PRG, the sum of the conservative assumptions results in an extremely conservative PRG.

Assumptions used in calculating the risk-based PRG for vinyl chloride which tend to overestimate potential risk include the following:

- Residents living in one location for 30 years is the upper bound (90th percentile).
- The probability of exposure to contaminated groundwater is very low (discussed above).
- Consumption of 2 liters of water per day represents the upper bound (90th percentile) of adult water consumption, one-half of which (1 liter per day) is consumed at work.
- Gastrointestinal absorption of ingested contaminants is assumed to be 100 percent (no matrix effect), but literature indicates that less than 100 percent of ingested contaminants is generally absorbed from the gastrointestinal tract.
- Carcinogenic potency factors are based on the assumption of no threshold for cancer but depending upon the chemical, true thresholds may exist and cancer repair mechanisms have been shown to exist.
- Dose-response data from studies on homogeneous animal populations are used to predict the response in a heterogeneous human population.
- Dose-response data from short-term animal studies are used to predict the effects of long-term human exposures.
- Dose-response data from effects observed at high doses are used to predict the adverse health effects following exposure to low levels in the environment.
- Risk additivity ignores possible antagonisms among chemicals.

Assumptions which tend to underestimate potential risk include the following:

- All compounds for which no analyses were performed or which were never detected in any sample were assumed to be absent from the site.
- Chemicals detected infrequently (less than 5 percent detection frequency) were not assessed.
- Chemicals with no available toxicity values (or with toxicity values withdrawn and under review) were not quantified in the risk assessment.
- Only those exposure routes that were considered to potentially contribute to risk were assessed.
- Risk additivity ignores possible synergism among chemicals.

The assumptions which tend to underestimate risk are not expected to adversely affect the protectiveness of the risk-based PRG because the assumptions that overestimate exposures provide a margin of safety which is more than sufficient to offset the assumptions which underestimate exposures.

3.4.2 Target Risk

In general, the EPA accepts PRGs based on 1E-06 risk. However, the EPA Office of Solid Waste and Emergency Response (OSWER) issued guidance to clarify the role of the baseline risk assessment to make risk management decisions such as determining whether remedial action is necessary at a site (OSWER Directive 9355.0-30). The memorandum emphasizes the following points:

> "Where the cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 1E-04, and the noncarcinogenic hazard quotient is less than 1, action generally is not warranted unless there are adverse environmental impacts. However, if MCLs or non-zero MCLGs are exceeded, action generally is warranted."

Other contaminant-specific ARARs may also be used to determine whether a site warrants remediation. Compliance with a chemical-specific ARAR generally will be considered protective even if it is outside the risk range, i.e., $>10^{-4}$ and $<10^{-6}$ (unless there are extenuating circumstances such as exposure to multiple contaminants or pathways of exposure).

The upper boundary of the risk range is not a discrete line at 1E-04, although EPA generally uses 1E-04 in making risk management decisions. A specific risk estimate close to 1E-04 may be considered acceptable if justified based on site-specific conditions. On the other hand, a risk manager may decide that a baseline risk level less than 1E-04 is unacceptable due to site-specific reasons, and that a remedial action is warranted.

The ROD should clearly justify the use of any non-standard exposure factors and the need for remedial action if baseline risks are within the generally acceptable risk range. The ROD should also include a table listing the FRGs and the corresponding risk level for any chemical of potential concern.

3.5 DETERMINATION OF REMEDIAL ACTION LEVELS

3.5.1 Remedial Action Objectives

The development of the RAO is presented in this section. Section 3.3.2 presented the assumptions used to develop the risk-based PRG for the residential adult. Based on these assumptions, the calculated PRG for the residential adult receptor is shown in Table 3.1. The risk-based PRG is also compared to the EPA MCL (1996a) for determining the most appropriate human health-protective remediation of groundwater at the IWTP/SCOBGW OUs site. Since LSZ groundwater is suitable for drinking in the vicinity of Tinker AFB, the EPA MCL is the most appropriate ARAR for groundwater protection.

Table 3.1
Comparison of Risk-based PRG and MCL for Determining the Proposed PRG

Chemical	Carcinogenic Risk PRG Concentration* (µg/L)	Noncarcinogenic Risk PRG Concentration (µg/L)	EPA MCL (µg/L)	**Proposed PRG (µg/L)**
Vinyl chloride	2.81	NTD	2	2

*Calculated for 1E-04 risk.
NTD = No noncarcinogenic toxicity data available for calculations.

The PRG calculation is based on the lower bound of the EPA acceptable target cancer risk range (1E-04). This level of protection is considered adequate based on the very low potential for exposure to groundwater. As previously discussed, the residential scenario provides a very conservative (health-protective) remediation level because the probability of current and future use of USZ and LSZ groundwater is expected to be very low. It is unlikely that a future private well would be placed in either the USZ or LSZ because alternate sources of water are available from surrounding municipal and base water supplies. Water for these supplies is taken from the PZ and/or surface water sources. Current exposure to USZ and LSZ water would also be limited since the majority of wells in the area have been plugged and residences have converted to city water. Also, the base does not use either USZ or LSZ groundwater. The six LSZ wells where vinyl chloride was detected are located on base and there is very low potential for off-base migration of contamination.

As shown in Table 3.1, the EPA MCL for vinyl chloride has been identified as the appropriate PRG. The ARAR-based PRG provides the more health-protective remediation concentration. This satisfies compliance with ARARs and is in agreement with EPA (1991b) guidance which advocates the use of health-based ARARs as PRGs.

As stated in the beginning of this section and in Section 4.2.1 of the *Guidance for Conducting Remedial Investigations and Feasibility Studies* under CERCLA (EPA, 1988c), the RAOs are for human health and for environmental protection. The site conditions (both on-base and off-base), have met the criteria for human health protection listed in the EPA RI/FS guidance. Oklahoma County has plugged and abandoned most of the domestic wells off-base. Except one residence along SE 29th Street, all addresses off-base have been connected to city water. The fact sheet, public meetings, and state and county regulatory and health agency involvement would prevent future drilling of domestic wells. On base the institutional control that allows no drinking water wells in the plume is much easier to implement. Thus, the RAO for environmental protection, i.e., restore groundwater aquifer, has to be achieved. The restoration goals are the risk-based PRGs at 10^{-4} risk level.

The EPA allows the use of remedial goals based on risks rather than MCLs for all carcinogens with MCLGs of zero. For the carcinogens with zero MCLGs, except vinyl chloride, the MCLs are set at 0.005 mg/L. This number represents the "feasible" level, taking cost into consideration. The MCL for vinyl chloride is 0.002 mg/L (EPA, 1990c). Because the MCLs are set considering cost factors and not specific risks, remediation goals can be set to risk-based levels associated with the groundwater.

3.5.2 Alternate Concentration Limits

The EPA *CERCLA Compliance with Other Laws Manual* (1988a) and the *Guidance on Remedial Action for Ground Water at Superfund Sites* (1988d) states that the alternate concentration limits (ACLs) are ARARs. The guidance further states that ACLs can be used as cleanup levels at the end of the remedial action, and only if the following conditions are met:

- The groundwater has known or projected point of entry into surface water, which is a reasonable distance from the facility boundary.
- There will be no statistically significant increase at the 95 percent confidence level of constituent concentrations occurring in the surface water in the discharge zone or at any point where constituents are expected to accumulate.
- Institutional controls will be implemented that will preclude human exposure to groundwater contaminants between the facility boundary and the point of entry into the surface water.

The IWTP/SC conditions meet these three criteria. Appendix C is the technical memorandum of ACLs development. Table 3.2 lists the proposed ACLs and the maximum concentrations at the point of compliance (POC). The POC is the western edge of the IWTP and is hydraulically downgradient.

Table 3.2 Alternate Concentration Limits of IWTP/SC Groundwater

Constituent	Proposed ACL (μg/L)	Maximum Concentrations at POC (μg/L)
PCE	40	330
TCE	200	380
1,1-DCE	35	27
cis-1,2-DCE	140	850
VC	1,000	520
Cr	1,500	920
Ni	1,500	350

Following ACL guidance (EPA, 1987 and 1988e), groundwater remediation is required because PCE, TCE, and *cis*-1,2-DCE exceeded the proposed ACLs. (The term "proposed" implies that the ACLs have not been officially approved by EPA.)

3.5.3 Discussion

It should be noted that Section 3.5.1 and 3.5.2 indicate the necessity of groundwater remediation. However, the action levels and the contaminants deciding the remediation are different. Section 3.5.1 indicates that vinyl chloride is the driving force for groundwater remediation with the goal of 2 μg/L. Section 3.5.2 indicates that vinyl chloride is not the reason for remediation because the maximum recorded concentration is below the proposed ACL, 1,000 μg/L. There is 500 times difference between the proposed PRG and the proposed ACL for vinyl chloride. The vinyl chloride plume is relatively small and limited to the close vicinity of IWTP on base. This is the reason that the proposed ACL is much higher than the RAO for vinyl chloride.

The ACL guidance states that if groundwater at the POC exceeds the ACL, groundwater remediation is required. The CERCLA/SARA requires remediation if there is a reasonable exposure to a receptor at a risk rate above one in 10,000. The solvent plumes are on base which provides a sound institutional control and there is no receptor that is now exposed to the USZ and LSZ groundwater. The baseline risk assessment (Parsons ES, 2000) and Section 3.5.1 are based on the assumption of human exposure, not observed, consumption by base workers, or people in the family housing area on base.

According to Risk Assessment Guidance for Superfund (RAGS) (EPA, 1989a), there is no exposure, there is no risk, and therefore, no groundwater remediation. (However, there is the "perceived" risk at Tinker AFB.) According to ACL guidance, once the contamination at the POC exceeds the ACL, groundwater remediation is required. In either case, the current Building 3001 pump-and-treat system is downgradient of the

IWTP/SCOGBW OUs and will capture the plume (see Section 2.9). But active remediation at the plume centroids near IWTP/SC would hasten the cleanup.

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SECTION 4

IDENTIFICATION AND SCREENING OF TECHNOLOGIES

4.1 INTRODUCTION

As previously discussed, two of the well groupings examined during the risk assessment contain vinyl chloride at concentrations above risk-based levels. These well groups are south of the groundwater flow boundary. General response actions and technologies potentially applicable to the remediation of contaminated groundwater are presented in this section. Typical response actions include institutional actions, source removal actions, plume containment, and/or treatment. General treatment technology categories include chemical treatment, thermal treatment, and *in situ* treatment.

Potentially applicable technologies for groundwater remediation at Tinker AFB are listed in Table 4.1. The various options were evaluated and screened for use based on their effectiveness, implementability, and relative cost. A summary of the screening process is presented below. The majority of the screening process is presented in table form. A final presentation of alternatives retained is shown in Figure 4.1.

4.2 INSTITUTIONAL ACTIONS

Institutional actions are those actions that do not treat the groundwater directly. Rather, they rely on restricting actions and natural processes. As required by the NCP, the no action alternative will be retained and evaluated as a baseline comparison. Natural attenuation, or intrinsic remediation, a process that involves naturally occurring degradation, would cause a reduction in mobility, toxicity, and volume of the plume. To monitor the effects of natural attenuation, a groundwater plume is sampled periodically and results are modeled to ensure that while natural processes are reducing contamination, the plume does not migrate offsite. Other institutional actions, including deed restrictions and long-term monitoring, will also be evaluated. However, deed restrictions may not be feasible for off-base properties not owned by Tinker AFB.

Table 4.1 Preliminary Screening of Remediation Technologies for Contaminated Groundwater

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementa-bility	Cost	Retain for Further Consideration
No action	None	None	Leave groundwater as is. No monitoring or investigation.	Consideration required by NCP. Contamination is not mitigated. Does not comply with action-specific ARARs.	Not effective	NA	None	Yes
Institutional control	Deed restrictions	None	All deeds for property within contaminated area would include restrictions on groundwater use only.	Contamination is not mitigated. Does not comply with chemical-specific ARARs.	Effective only in preventing future well installation into the aquifer.	May be difficult to implement off base	Low	No
	Continued monitoring	Natural attenuation	Contamination will naturally degrade and dilute given enough time. Monitoring allows for tracking of plume migration. Usually combined with deed restrictions.	Additional plume monitoring and modeling may be necessary. Intermediate decomposition products may be more toxic than original contaminants. Input from regulatory personnel will be needed for implementation.	Moderately effective in gauging plume migration and natural attenuation.	Easily implemented; long-term maintenance	Low	Yes
Plume containment	Hydraulic barriers	Injection wells	Injection wells used to create area with higher hydraulic head to change direction and speed of plume migration.	Existing contamination is not mitigated. Contamination may spread vertically. Plume must be fully defined. Additional wells may be required.	Not generally effective because of low soil permeability and multiple layers.	May be readily implemented	Moderate	No
		Extraction wells	Line of extraction well or well points are installed and pumped to capture the plume. Trenches may also be used to intercept and collect groundwater.	May be used as a barrier and for extraction of groundwater for treatment. Complete definition of plume is required. Continued long-term monitoring and mainten-ance required.	Effective in limiting further horizontal migration, does not, by itself remediate. Long periods of time needed to remove several pore volumes.	Readily implemented	Moderate to high	Yes, as part of P&T program.

Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementa-bility	Cost	Retain for Further Consideration
Plume containment (cont.)	Vertical barriers	Slurry walls, grout curtains, sheet-piling cut-off walls	Low permeability cut-off walls are installed below ground to contain, capture, or redirect groundwater flow. Leachate recovery system must be included.	Full extent of plume must be defined. Does not mitigate contamination. May be used in conjunction with *in situ* treatment.	Limited, due to inability to create a totally impervious wall.	Difficult to construct; depth limitations	High	No
Source containment	Capping	Low permeability caps and/or liners	Source sites capped with low permeability clays, geomembrane, asphalt or a combination to prevent surface water infiltration and creation of leachate.	Requires long-term monitoring.	Generally effective in limiting further waste migration. Does not abate contamination caused by waste below the water table.	Easily implemented	Moderate	No
	Vertical barriers	Upgradient slurry walls, grout curtains, sheet-piling, cutoff walls	Low permeability walls upgradient prevent groundwater flow through source located below the water table.	Full extent of plume must be defined. Does not mitigate contamination. May be used in conjunction with *in situ* treatment.	Limited, due to inability to create a totally impervious wall.	Difficult to construct; depth limitations. Length is smaller than contaminant plume.	Moderate to high.	No
Source removal	Excavation	None	Removal of contaminated soil would require excavation and transporting to a RCRA disposal facility.	Requires destruction of surface structures. Soils may require treatment to meet land disposal restriction requirements.	Most effective in source and hot spot control.	May be difficult and dangerous to implement	High	No
Groundwater extraction	Wells	Wellpoints	Good for soils with low to high hydraulic conductivities and for heterogeneous materials.	Used for wells less than 20 feet in depth. Capacity 0.1-25 gpm, spacing 5-10 feet.	Effective when radius of influence overlaps. Cannot be used at the depths required. Also may act as SVE if screened above water.	Very easily implemented and maintained	Moderate to high	No

Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementa-bility	Cost	Retain for Further Consideration
Groundwater extraction (cont.)	Wells (cont.)	Ejector wells	Good for soils with moderate hydraulic conductivities and for heterogeneous materials.	Used for wells greater than 20 feet. Capacity of 0.1-40 gpm, spacing 20-40 feet.	Potentially effective. This technology is currently in use at Tinker AFB.	Fairly easily implemented and maintained	Moderate	Yes
	Interceptor trench	None	Trenches are dug then backfilled with a porous material to collect ground-water. Water is removed by pumping.	Used in slow recharge areas. May be limited by depth.	Not effective at the depths required at Tinker AFB.	May be readily implemented	Moderate to high	No
Post extraction treatment	Physical treatment	Air stripping	Removal of relatively volatile dissolved organic compounds using air as the gas for mass transfer.	May need to treat off-gas with activated carbon. Pretreatment to remove suspended solids may be required.	Has proven very ef-fective for removal of volatile organics.	Easily implemented	Moderate	Yes
		Activated carbon treatment	Extracted groundwater allow-ed to flow through a series of packed bed reactors. Organic molecules are adsorbed to the carbon granules.	Periodically, the carbon granules must be regenerated or disposed of. Pretreatment may be required to remove suspended solids.	Has proven very ef-fective for removal of volatile organics.	Easily implemented	Moderate to high	Yes
		Filtration	Suspended solids are remov-ed from solution by forcing the fluid through a porous medium.	Requires backflushing to unclog filter. Usually used as part of a treatment train.	Has proven very ef-fective for removal of suspended solids.	Easily implemented	Low	Yes
		Sedimenta-tion	Relies upon gravity to remove suspended solids. Collection of sediments in a tank or pond. A sediment removal system must be incorporated.	Generates a large volume of sludge and is relatively slow. Tanks would have to remain covered and air treated to remove volatile organics.	Effective for settleable solids.	More difficult to implement than other technologies	Low	Yes

Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementability	Cost	Retain for Further Consideration
Post extraction treatment (cont.)	Physical treatment (cont.)	Reverse osmosis	The application of sufficient pressure to concentrate solution to overcome osmotic pressure and force the net flow through the membranes toward the dilute phase.	Pretreatment required for removal of solids.	Very effective for removal of organics and dissolved inorganics.	More difficult to implement than other technologies	Moderate to high	No
	Chemical treatment	Ultraviolet (UV) light catalyzed oxidation with hydrogen peroxide or ozone	Contaminated groundwater is mixed with hydrogen peroxide or ozone in a reactor and exposed to ultraviolet light. The chlorinated organics are oxidized into mineral components.	No vapor or other emissions. No separate wastewater or sludge created needing disposal or additional treatment. May require pretreatment to remove solids and metals from groundwater.	Very effective for destroying organics.	More difficult to implement than other technologies	Moderate to high	No
		Precipitation/ flocculation	Removal of metals as hydroxides or sulfides is the most common precipitation application. Lime or sodium sulfide is added in a rapid mixing tank. Mixture flows to a flocculation chamber and precipitation occurs, followed by filtration or sedimentation.	Selection of suitable precipitate or of flocculant and dosage determined in the laboratory. Generates a large volume of sludge which must be disposed of.	Has proven very effective for removal of dissolved metals.	Easily implemented	Low to moderate	Yes
		Catalytic thermal oxidizer	Contaminated air, off-gas from air stripper unit, enters the system through a preheater, then is routed to a combustion chamber that oxidizes the VOCs. The hot cleaned gases are then rerouted through the preheater as a heat source for incoming air.	Appropriate for low concentration of VOC emissions, achieving a destructive removal efficiency of 95 percent or better. May require acid gas controls if high concentrations of chlorinated materials are oxidized.	Very effective for destroying organics.	More difficult to implement than other technologies.	Moderate to high	Yes

Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementa-bility	Cost	Retain for Further Consideration
Post extraction treatment (cont.)	Biological treatment	Aerated lagoons, trickling filters, anaerobic digestion, activated sludge	Microorganisms are used to break down organic contaminants. Existing SWTP uses biological treatment. IWTP uses activated sludge system.	Biosolids generates large sludge waste stream. Trickling filters and anaerobic digestion are prone to disruptions.	Effective for some organics. Others may be toxic.	More difficult to implement than other technologies	High	Yes - as existing IWTP
Discharge of groundwater		Reinjection	Reinject treated groundwater to aquifer.	Can aid in contaminant migration, can be used as hydraulic gradient control, could help in cleaning subsurface soils and decrease extraction time.	Not effective for very large plumes or low permeability soils.	Easy to implement; moderate to maintain; difficult to permit.	Moderate	No
		Deep well injection	Discharge treated or untreated groundwater to regulated deep well injection system.	Water would have to be transported to disposal facility.	Effective	Fairly easy to implement	High to very high	No
		Surface water	Discharge treated groundwater to on-site surface water.	Continual analysis of treated water prior to discharge.	Effective	Requires NPDES permit	Moderate to high	No
		POTW (publicly owned treatment works)	Discharge treated or untreated groundwater to local POTW.	Analysis of water prior to discharge required.	Effective	Requires approval from local sewage treatment authority	Moderate	Yes
		Irrigation	Discharge treated groundwater to irrigate golf course or other vegetation.	Requires analysis of treated water and permission.	Effective	Poor with public perception	Moderate	No
		Industrial water supply	Discharge treated groundwater to industrial water supply system.	Analysis of treated water and permission.	Effective	Easy to implement	Moderate	Yes

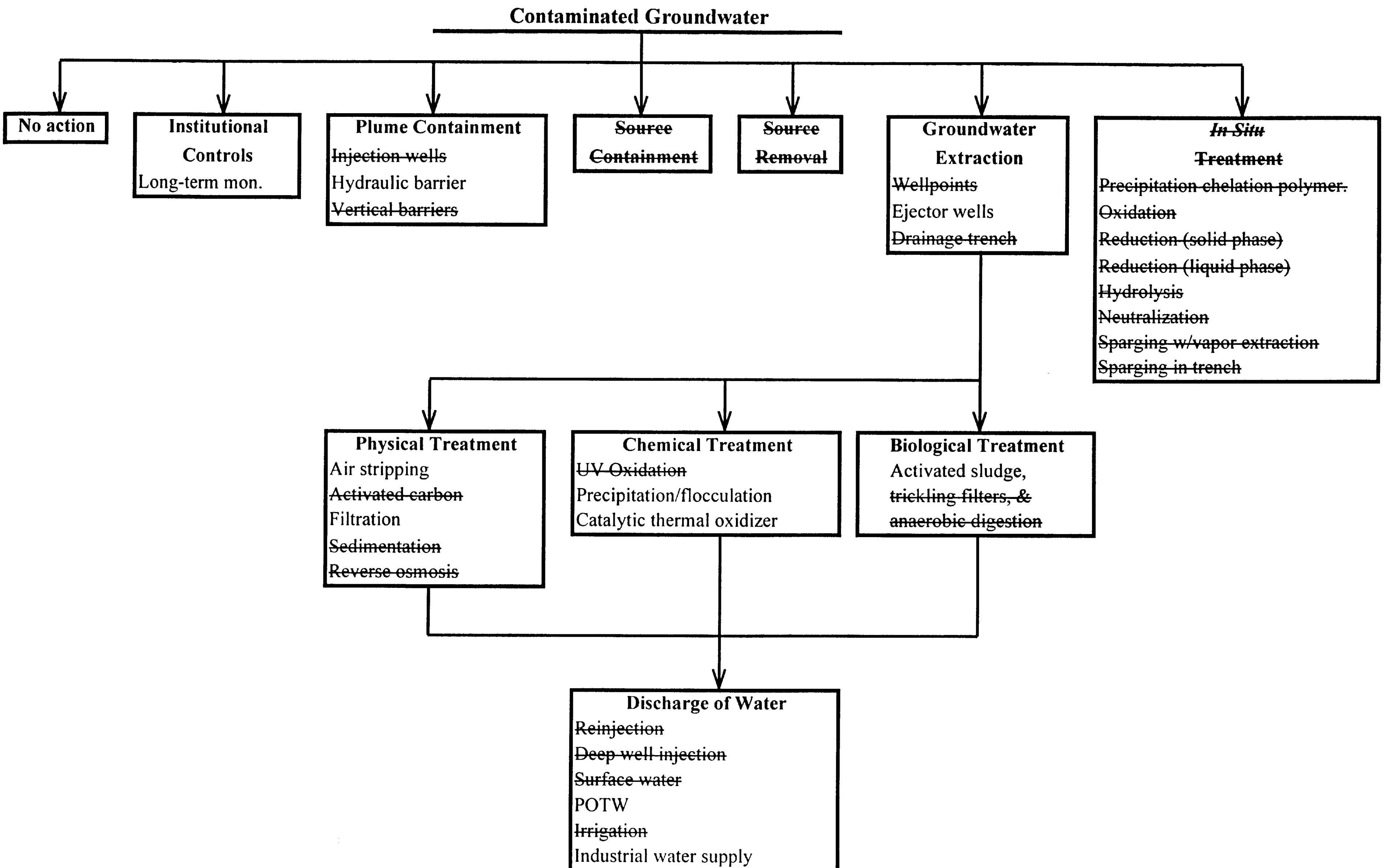
Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementability	Cost	Retain for Further Consideration
***In situ* treatment**	Biological treatment	Biodegradation/biorestoration	Biological modification or destruction of contaminants. Nutrients may be injected to enhance native microorganisms to biodegrade contamination.	Chlorinated solvents not easily degraded, may have toxic intermediate breakdown products. Dispersion of nutrients difficult in soil.	Can be effective. Difficult to evaluate performance.	Proper evaluation and design required for implementation	Moderate	No
	Chemical/ physical treatment	Precipitation chelation polymerization	Precipitation is the most developed technology. Precipitation can occur by adding sulfides, phosphates, hydroxides, or carbonates to the groundwater.	Care must be taken that more pollution is not created. Metals can become redissolved. May clog soils and hinder other remedial technologies.	Not effective for organics.	Readily available	Moderate	No
		Oxidation	Ozone, hypochlorite, or hydrogen peroxide are injected into groundwater to increase the oxidation state of compounds. The contaminants are detoxified, mobility is increased, or made more amenable to biological degradation.	May create more contamination. Organic contaminants are resistant to oxidation under ambient conditions.	Not effective in low permeable soils. Difficult to distribute oxidizer evenly throughout the aquifer.	Readily available	Moderate to high	No
		Reduction (solid phase)	Groundwater flows through a treatment cell filled with reducing agent such as iron.	Innovative technology. Not fully field tested. Depth may be a construction limitation.	Unknown	Difficult to monitor results; treatment cell is readily constructed.	High	No
		Reduction (liquid phase)	Same as above only reducing agents are introduced into groundwater.	Organics may be resistant without a catalyst. By-products of dechlorination may be more toxic.	Difficult to distribute reducing agent through out aquifer.	Readily available	Moderate to high	No

Table 4.1, continued

General Response Action	Remedial Technology	Process Options	Description	Screening Comments	Effectiveness	Implementa-bility	Cost	Retain for Further Consideration
***In situ* treatment (cont.)**	Chemical/ physical treatment (cont.)	Hydrolysis	Water with lime or NaOH is injected into groundwater. The mixture causes a reaction and molecules divide.	Not applicable to contaminants detected at Tinker AFB.	Not effective	Readily available	Moderate	No
		Neutraliza-tion	Neutralization involves in-jecting dilute acids or bases into the groundwater to adjust the pH. This may serve as a pretreatment prior to oxidation, precipitation, or reduction.	Not applicable to contaminants detected at Tinker AFB.	Not effective	Readily available	Moderate	No
		Sparging with vapor extraction	Air is injected into aquifer and strips volatile organics from water. Vapor extraction system is installed in the unsaturated zone to aid in mass transfer.	Transport difficult in low perme-ability soils. Off-gas may need to be collected and treated.	Can be effective at shallow depths.	Readily available	Moderate	No
		Sparging in a trench	Same as above only treatment occurs in a trench filled with a high permeability material.	Placed downgradient of a plume. Overcomes transport difficulties in low permeability soils.	Can be effective. Depth limitations due to trench construction.	Readily available	Moderate	No

Figure 4.1 Alternatives Retained for Remediation of Contaminated Groundwater
IWTP/Soldier Creek Off-Base Groundwater Operable Units



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4.3 SOURCE REMOVAL

Source removal can be used to prevent additional generation of contaminated groundwater. When a well-defined, concentrated, continuing source is present, such as a leaking tank or highly contaminated soil, source removal is the most effective way to prevent ongoing groundwater contamination. However, no such clearly-defined, concentrated sources were found during the remedial investigation (Parsons ES, 1998), nor during the IWTP RFI (Parsons ES, 1994). Therefore, source removal is not an option for remedial action because of the minimal or nonexistent amount of contamination.

4.4 CONTAINMENT TECHNOLOGIES

Containment technologies can address either the contamination source or the contaminated groundwater. Source containment options include capping and vertical barriers. When the source is contaminated soil above the water table, capping minimizes infiltration and leachate generation. Migration of groundwater through a source (source containment) below the water table can be prevented with a vertical barrier, such as a slurry wall, grout curtains, or sheet-piling. These technologies act as physical barriers which contain and/or divert groundwater flow. Physical barriers do not impede vertical migration of contaminants, do not mitigate contamination, and may be difficult to construct. The depth and vertical nature of the aquifers at Tinker AFB limit the effectiveness of physical barriers. Therefore, the use of physical barriers as a source containment technology was not retained during the screening process.

In general, groundwater containment technologies may be applicable remediation technologies at Tinker AFB. These technologies are intended to halt the spread of contaminated groundwater. There are two basic types of containment: hydraulic barriers which control gradient and physical barriers.

Hydraulic barriers are comprised of injection wells, extraction wells, or a combination of both. They are designed to influence hydraulic gradients and alter the flow of groundwater. Injection wells add water to the formation creating a pressure ridge to alter the groundwater flow. Extraction wells are placed such that their radii of influence overlap and capture the plume.

Hydraulic barriers, themselves, do not mitigate contamination, and they can be difficult to implement in formations with multiple layers or low permeabilities. The interbedded nature of the aquifer at Tinker AFB impedes the effectiveness of hydraulic barriers, particularly injection well barriers. Given the hydrogeologic characteristics of the site, hydraulic barriers, as the sole groundwater remediation technology, were not retained for future consideration. However, the use of extraction wells as part of a pump-and-treat program will be evaluated further.

Physical or vertical barriers which can be used to contain a source can also be used to contain, capture, or redirect groundwater flow. However, the same problems described above for source containment prevent use of vertical barriers for groundwater containment at Tinker AFB. Vertical barriers do not mitigate contamination, and they would be difficult to construct due to the depth of the aquifer.

4.5 TREATMENT TECHNOLOGIES

In general, contaminated groundwater may be removed and treated with a variety of technologies to reduce contamination, treated *in situ*, or allowed to remain in place where natural degradation and dispersion will eventually dilute the contamination. The following is a discussion of the treatment options reviewed.

4.5.1 Groundwater Recovery

Two common techniques used to recover groundwater include installation of well fields or interceptor trenches. A well field consists of several wells spaced closely together which are pumped to intercept the plume and recover the groundwater. A well collection system is already in place at Building 3001. Therefore, this proven technology will be retained for further consideration.

An interceptor trench is a vertical trench placed downgradient of the contaminated groundwater to intercept the contaminant plume. The trench is filled with materials which have greater permeability than the surrounding soil. Water in the trench is pumped out as it is collected. The use of an interceptor trench is limited in depth, and existing structures such as buildings, parking lots, and runways render this alternative to be not feasible at Tinker AFB. Therefore, trenches will not be retained for further consideration.

4.5.2 Physical Treatment of Contaminants

Physical treatment of contaminated groundwater removes contamination from the water and deposits it onto another medium or emits it as an off-gas. Five physical treatment options were identified: air stripping, activated carbon adsorption, filtration, sedimentation, and reverse osmosis. Some of these alternatives treat organic contaminants and some treat inorganic contaminants. Each of these alternatives are described below.

4.5.2.1 Air Stripping/Steam Stripping

Air stripping and steam stripping are mass transfer processes in which organics are transferred from the groundwater to air or steam. Steam stripping is used when the contaminants of concern have low volatility. Air stripping does not destroy the contaminants, only removes them from the groundwater. Pretreatment may be required to remove suspended solids. The off-gas may require additional treatment prior to release into the atmosphere. Air stripping is currently being used at Tinker AFB to treat the groundwater extracted from the Building 3001 collection system. Steam stripping will not be retained in the screening process because air stripping is effective for the contaminants of concern and is more economical than steam stripping. Air stripping will be evaluated as part of the remedial design.

4.5.2.2 Activated Carbon Adsorption

Activated carbon adsorption is a mass transfer process in which dissolved organic contaminants are removed from groundwater by adsorption onto activated carbon. It is also an effective treatment for organic vapors in gaseous streams. Packed bed reactors are used to contact the carbon and water. Nonvolatile organic components, such as phenols, can also be removed by carbon adsorption. The bed life is a function of the concentration of organics in the water. Once the carbon is saturated with organics it must be regenerated or disposed of. Carbon adsorption is a highly effective form of treatment for low levels of organic contamination. It is less effective for vinyl chloride due to its mobility and high volatility. It is subject to fouling by suspended solids, metals, and microbe growth, therefore pretreatment to remove solids may be required. The groundwater treatment system at Tinker AFB currently uses activated carbon adsorption to treat off-gas from the air stripper. Carbon adsorption will be retained for additional evaluation.

4.5.2.3 Filtration

Filtration is the process of separating suspended solids from their liquid by forcing the latter through a porous medium. Filtration may be required if the groundwater is high in suspended solids (including metals). The simplest form of filtration is to pass the groundwater through a bed of sand. Suspended solids attach to the sand particles, and the water continues through the bed. The sand filter removes suspended solids by solid-solid contact. The groundwater treatment system at Tinker AFB uses filtration as its final step; therefore, filtration will be retained for additional evaluation.

4.5.2.4 Sedimentation

Sedimentation is the simple process of allowing suspended solids to fall by gravity. Water with suspended solids must enter a tank without causing turbulence in the tank and reagitiating already settled solids. The water must be evenly distributed throughout the tank in order to make maximum use of the surface area of the clarifier. The groundwater treatment system at Tinker AFB currently uses sedimentation to remove suspended solids. Therefore, sedimentation will also be retained for additional evaluation.

4.5.2.5 Reverse Osmosis

In reverse osmosis systems, water is forced under high pressure through a membrane. The membrane only allows passage of water and rejects inorganic material. However, low-molecular weight organic compounds commonly pass through the membrane. Furthermore, reverse osmosis systems are expensive to operate due to the high pressures required; therefore, this alternative will not be retained for further evaluation.

4.5.3 Chemical Treatment

4.5.3.1 Ultraviolet (UV)/H_2O_2 Oxidation

UV oxidation is a process in which an oxidizer (hydrogen peroxide or ozone), together with ultraviolet light, is used to oxidize organic and some inorganic compounds. This process ideally results in complete mineralization of the organic compounds. That is, all organics are converted to carbon dioxide, water, and chlorine. UV oxidation treatment produces no waste streams which would require additional treatment. UV systems have high electricity costs and may also have high maintenance costs. If ozone is used as the oxidizer, additional equipment is needed to generate the ozone onsite. The UV lights are sensitive to fouling from naturally occurring groundwater constituents such as solids, iron, and the growth of microorganisms. UV oxidation using peroxide will not be evaluated as part of the remedial design because less expensive alternatives are available.

4.5.3.2 Precipitation/Flocculation

Since sedimentation will not remove all suspended solids within a reasonable time-frame, additional steps can be taken to remove remaining suspended particles. All of the particles have the same charge on their surfaces (usually negative) which keeps them separated. The first step of flocculation is to neutralize the charge (with lime, alum, ferric chloride, or others) so the particles can come into contact with each other with gentle mixing. Agents can also be added to cause metals to precipitate. Since this alternative is currently in operation at the Tinker AFB groundwater treatment plant, it has been retained for further evaluation.

4.5.3.3 Catalytic Thermal Oxidizer

A catalytic thermal oxidizer could be used to oxidize volatile organic compounds (VOCs) in off-gas from an air stripper unit. This alternative is appropriate for treatment of low VOC concentrations. Since this alternative is very effective at destroying VOCs, it has been retained for further evaluation.

4.5.4 Biological Treatment

Bioremediation systems include aerated lagoons, activated sludge (biosolids), trickling filters, and anaerobic digestors. The mixing process used in aerated lagoons may result in organic loss due to stripping rather than biodegradation. Aerated lagoons also produce sludge which must be disposed. Trickling filter and anaerobic reactors require relatively constant feed rates and have long startup periods. The biological treatment processes may have difficulty achieving the remedial action objectives if groundwater alone is being treated. Therefore, new aboveground bioremediation systems will not be retained in the screening process. However, the biological units at the IWTP may be an effective alternative. Treatment at the IWTP will be retained.

4.6 DISCHARGE OF TREATED GROUNDWATER

Six alternatives for disposal of treated groundwater were identified: reinjection, deep well injection, discharge to surface water, discharge to public-owned treatment works (POTW), irrigation, and discharge to industrial water supply. Reinjecting treated groundwater to the aquifer was not retained due to the difficulties that would be encountered in permitting. Deep well injection was not retained due to the associated high costs. In June 1996, Tinker AFB no longer discharged treated water from the IWTP to East Soldier Creek under an NPDES permit. For this reason, the discharge to surface water option was not retained. Finally, the irrigation alternative was not retained due to poor public perception, cost of transportation, and monitoring requirements.

Two disposal options were retained for further consideration: (1) discharge treated groundwater to the local POTW (either via the IWTP or directly) and (2) discharge to the Tinker AFB industrial reuse distribution system (via the groundwater treatment plant).

4.7 *IN SITU* TREATMENT

In situ treatment is often preferred over aboveground treatment because the costs are generally lower and there are no disposal issues. However, *in situ* treatment is generally more difficult to implement and monitor than aboveground treatment technologies. *In situ* treatment can be divided into chemical/physical treatment and biological treatment. Many of the *in situ* alternatives have the same premise as the aboveground *(ex situ)* alternatives. The following is a discussion of the *in situ* treatment options reviewed.

4.7.1 Physical/Chemical Treatment

4.7.1.1 Precipitation/Chelation/Polymerization

Precipitation/chelation/polymerization is similar to the aboveground alternative in that an agent or polymer is added which causes inorganics to precipitate. Precipitation can occur by adding sulfides, phosphates, hydroxides, or carbonates to the groundwater. However, this alternative has several drawbacks. Some inorganics could redissolve. In addition, the soils may become clogged with precipitate, hindering other remedial technologies. For these reasons, this alternative has not been retained.

4.7.1.2 Oxidation

Ozone, hypochlorite, or hydrogen peroxide is injected into groundwater to increase the oxidation state of compounds under this treatment alternative. Oxidation can result in contaminant detoxification, increased mobility, and more likely occurrence of biodegradation. However, organic contaminants are resistant to oxidation under ambient conditions. Furthermore, it is difficult to evenly distribute oxidizer throughout the aquifer. For these reason, oxidation has not been retained.

4.7.1.3 Reduction (liquid phase and solid phase)

Solid phase reductive dehalogenation is a remediation technology which uses a zero valence metal formulation to detoxify dissolved chlorinated organic chemicals. The material is placed in trenches where the water can flow through. The chlorine atoms are replaced with hydrogen atoms and the resulting chemical is less toxic. It will not be retained for further evaluation due to the depth limitations of trenches.

4.7.1.4 Hydrolysis and Neutralization

Hydrolysis involves the injection of groundwater with lime or sodium hydroxide, and neutralization involves the injection of groundwater with dilute acids or bases. However, these treatment alternatives are not applicable to contaminants detected at Tinker AFB, so they have not been retained.

4.7.1.5 Sparging

In situ stripping or sparging is a mass transfer treatment process in which volatile organics are stripped from the groundwater by injecting air into the formation. This technology may be difficult to implement in the aquifer materials at Tinker AFB. Low permeability soils impede dispersion of the air causing individual sparging wells to have small radii of influence. Results may be improved when sparging is used together with vapor extraction in the unsaturated zone to improve transport by increasing air pressure gradients. This technology was removed from consideration due to the difficulties in implementation at Tinker AFB.

4.7.2 Biological Treatment

Bioremediation may be applied as an *in situ* treatment process. Oxygen, nutrients, and/or specialized microorganisms may be added to the formation to improve the degradation rates. Active *in situ* bioremediation will not be evaluated for use at Tinker AFB. The low hydraulic conductivity, great depth, and noncontinuous nature of the aquifer would impede the transport of nutrients throughout the aquifer. However, natural bioremediation as part of the natural attenuation option will be retained.

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SECTION 5

DEVELOPMENT AND SCREENING OF ALTERNATIVES

5.1 INTRODUCTION

The remedial technologies which passed the preliminary screening process have been assembled into alternatives to be considered for remediation.

Preliminary screening is performed for each alternative to consider three broad criteria: effectiveness, implementability, and cost. The purpose of this screening is to identify the alternatives that are technically feasible and as a result reduce the number of alternatives retained for detailed analysis. The alternatives determined feasible will be retained for detailed analysis (Section 6). The no action alternative will be retained to provide a basis for comparison as specified in the EPA guidance (EPA, 1988a).

For the purpose of this evaluation, the general term "divide" is used to describe the three-dimensional hydraulic divide made up of the divides related to each groundwater layer.

5.2 DEVELOPMENT AND SCREENING OF ALTERNATIVES

The purpose of this section is to combine applicable treatment technologies into remedial action alternatives. A variety of alternatives were assembled to address the groundwater contamination north and south of the groundwater divide. The alternatives considered for remedial action include: no action, limited action (continued monitoring), and a pump and treatment system.

Each side of the divide was evaluated independently in formulating remediation alternatives. Alternatives for north of the groundwater divide, identified as N-1, N-2, and N-3, and south of the groundwater divide, identified as S-1, S-2, and S-3, are described below.

5.2.1 North of the Groundwater Divide

The area north of the groundwater divide lies primarily off base (as shown in Figure 2.11). Thallium was identified as the only compound contributing to risk levels in this area (Parsons ES, 2000). However, as explained in Section 2.8.1.5, thallium contamination is not considered base related, therefore, will not be remediated. (See Federal Register 55(145):30796-30884 on Corrective Action for SWMU. The preamble states that it is not the EPA's intent for facility owner to clean up natural groundwater contamination.) Other metals concentrations north of the divide do not exceed MCLs and are considered to be representative of natural conditions. TCE in two wells north of the composite divide location (1-81 and TOB-8) was detected at concentrations of 5.3 μg/L and 11 μg/L, respectively. However, these detections were in the layer 7 well, and the actual layer 7 groundwater divide is north of both well locations (layers 3 and 5 divides are south of both wells), and upgradient of Tinker AFB. Therefore, although well 1-81 and TOB-8 were nominally in the well group north of a composite divide in the risk assessment (Parsons ES, 2000) for reasons of this composite divide, the contamination is south of the three-dimensional divide used in this evaluation. A summary of the screening processes is presented in Table 5.1.

5.2.1.1 Alternative N-1. No Action

The no-action alternative assumes no further remedial activities will be undertaken at the site. It is the baseline for comparison with the other alternatives for the IWTP/SCOBGW OUs.

Effectiveness: The no action alternative will not reduce the mobility, toxicity or volume of contamination. The volume of the contaminated groundwater may actually increase as the contaminants migrate throughout the media. However, because the contaminants of concern are currently below acceptable risk levels, the no action alternative is considered to be moderately effective.

Implementability: There are no barriers to implementation.

Cost: There are no costs associated with this alternative.

5.2.1.2 Alternative N-2. Limited Action (Continued Monitoring)

This alternative includes institutional control such as groundwater monitoring. Annual groundwater sampling events using the existing monitoring wells will monitor concentrations of contaminants listed in Table 2.6, including TCE but excluding thallium. The existing monitoring wells appear to be adequate to monitor the current groundwater conditions in the area. Hence, the installation of additional wells is not included in the evaluation of this alternative.

Table 5.1 Summary of Alternatives North of Groundwater Divide

Alternative	Effectiveness	Implementability	Potential Community Effects	Potential Community Concerns	Cost
N-1 No Action	Moderate: Contaminants of concern presently do not exceed acceptable risk levels.	No action is necessary.	Moderate: Existing concentrations not monitored or reduced.	Poor: Potential concerns are not addressed.	No cost
N-2 Continued Monitoring	Moderate: Contaminants of concern presently do not exceed acceptable risk levels. Provides continued information about contaminant concentrations and migration.	Good: Monitoring is an established program. Potential access difficulty for new wells.	Good: Existing concentrations are monitored.	Good: Potential concerns regarding contamination and migration are addressed.	Low
N-3 Hydraulic Controls/ Treatment	Moderate: Reduces potential for continued contaminant contact with groundwater.	Poor: Elevated concentrations scattered throughout large area. Potential access difficulties for new wells.	Poor: Treatment may alarm community unnecessarily.	Good: Potential concerns are addressed. However, treatment system may alarm community.	Very High

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Effectiveness: The limited action alternative will not reduce the mobility, toxicity or volume of contamination. The volume of the contaminated groundwater may actually increase as the contaminants migrate throughout the media. Monitoring of the contamination would identify increasing contaminant concentrations, signaling the base of possible unacceptable levels of contamination. If concentrations were to exceed acceptable risk levels, measures can be readily implemented to mitigate the contamination. Overall protection of human health and the environment will be provided under this alternative.

Implementability: This alternative is easily implemented. The existing wells can be used to collect samples for analysis to monitor appropriate groundwater contamination. A monitoring work plan, including contaminant action levels and a monitoring schedule, will have to be created prior to initiating groundwater sampling.

Cost: The cost of annual continued monitoring of existing wells is low. If monitoring must continue for a long period, however, the present-worth costs of monitoring may not appear significantly lower than those for capital-intensive or maintenance-intensive options operating within a shorter time frame.

This alternative will be retained for detailed evaluation.

5.2.1.3 Alternative N-3. Hydraulic Control, Treatment and Off-site Disposal

This alternative involves installing recovery wells and treating the groundwater to remove metals and discharging treated water to a local POTW. Hydraulic control involves obtaining permission from the land owners to install new recovery wells.

Effectiveness: The hydraulic control and treatment aspects of this alternative use proven technologies. When the contaminant plume is distinct, hydraulic control can effectively contain the groundwater contaminants within the pumping zone of influence, and is generally effective at remediating groundwater. However, groundwater contamination north of the divide is very spotty with no defined plume, limiting the effectiveness of a recovery well system.

Implementability: The hydraulic control and treatment alternative uses readily available equipment and traditional technologies which pose no implementation limitations assuming that a pretreatment agreement can be reached with the local POTW and permission is gained from the land owners for the installation of new recovery wells.

Cost: The overall cost for this alternative is very high relative to the other north groundwater divide alternatives.

Because of the lack of a defined contamination plume and cost considerations this alternative will not be retained for detailed evaluation.

5.2.2 South of the Groundwater Divide

This area lies primarily on base. The contaminant identified in the risk assessment as contributing to excess risk is vinyl chloride. The contaminants that exceeded the proposed ACLs are PCE, TCE, and *cis*-1,2-DCE. A summary of the screening processes is presented in Table 5.2.

5.2.2.1 Alternative S-1. No Action

The no-action alternative assumes no further action will occur at the site. It is the baseline for comparison with the other alternatives.

Effectiveness: The no action alternative for the south groundwater divide area should meet the remedial action goals for the IWTP/SCOBGW OUs even though the concentration of vinyl chloride in groundwater is currently exceeding both acceptable risk limits and the applicable MCL. Over a period of time, the Building 3001 pump-and-treat system, will reduce the mobility, toxicity, and volume (MTV) of vinyl chloride.

Implementability: There are no barriers to implementation.

Cost: There are no costs associated with this alternative.

5.2.2.2 Alternative S-2. Natural Attenuation with Monitoring and Institutional Controls

The dominant mechanisms causing natural attenuation of vinyl chloride and TCE are biodegradation, dispersion, dilution from recharge, sorption, and volatilization. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous by-products. Intrinsic bioremediation occurs when indigenous micro-organisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Natural attenuation mechanisms (including biodegradation) can be very effective in reducing contaminant concentrations and mass in groundwater. The effectiveness is further enhanced when natural attenuation is used in conjunction with source removal or when a portion of a plume is isolated from the source area. Current pumping in the vicinity of Building 3001 serves to isolate the eastern and northeastern portions of the plume from the source area(s). The detection of vinyl chloride at monitoring well 1-50AR at 610 μg/L indicated that natural biodegradation of

Table 5.2 Summary of Alternatives South of Groundwater Divide

Alternative	Effectiveness	Implementability	Cost
S-1 No Action	Moderate: Some reduction in mobility, toxicity, and volume.	No action will be implemented.	No cost
S-2 Natural Attenuation with Monitoring and Institutional Controls	Moderate: Some reduction in mobility, toxicity, and volume. Provides continued information about contaminant concentrations. Contaminant plume within the capture zone of existing Building 3001 pump-and-treat system.	Good: Monitoring is an established program.	Low
S-3 Upgrade Existing Groundwater Extraction System	Good: Installation of new recovery wells will increase recovery zone of existing extraction system.	Very good: Installation of new recovery wells is easily implemented.	Moderate
S-3-1 Upgrade Existing Groundwater Treatment System	Good: The existing system is sufficiently designed to handle the contaminant of concern. The potential problem of controlling vinyl chloride emissions is addressed.	Very good: Modification to the existing system is easily implemented.	Moderate
S-3-2 Pretreatment for Vinyl Chloride with S-3-1 Treatment Option	Very good: The new system is designed to remediate and treat VOCs and their potential emissions.	Moderate: More difficult to implement than other treatment technologies.	High

Table 5.2 Summary of Alternatives South of Groundwater Divide Continued

Alternative	Effectiveness	Implementability	Cost
S-3-3 New Treatment System	Good: A new system for treatment of recovered groundwater could be effective.	Moderate: Technologies are readily available.	Very high
S-3-4 IWTP Treatment	Moderate: The IWTP is currently designed to handle contaminants. The IWTP currently does not have adequate secondary containment. Potential problem of controlling vinyl chloride emissions.	Very good: Existing IWTP would be able to handle additional stream.	Low
Disposal Alternative Industrial Wastewater Reuse	Good: The industrial reuse system provides for an effective use of treated waters.	Very good: System is already in existence.	Low
Disposal Alternative POTW	Good: Routing treatment effluent waters to Oklahoma City POTW along with IWTP wastewaters is effective.	Moderate: Ongoing discussions with Oklahoma City officials may limit amount of water or effluent concentrations.	Low

chloride at monitoring well 1-50AR at 610 μg/L indicated that natural biodegradation of chlorinated solvents is occurring on base. Dr. Robert Hinchee (Hinchee, Robert, 1996) commented that the high iron content in the formation may be conducive to dechlorination, in addition to the anaerobic biodegradation.

Implementation of natural attenuation will initially require annual groundwater monitoring to confirm the efficacy of this remedial solution. During the first year of monitoring, one round of samples should be collected and analyzed for parameters useful for evaluating natural attenuation, including geochemical parameters and by-products of biodegradation processes. Analysis of the data will yield information that can be used in a numerical or analytical groundwater contaminant fate and transport model. A site specific fate and transport model could be coupled to the existing basewide groundwater flow and solute transport model, or a simple model such as Bioscreen or Biochlor could be used to make predictions regarding plume migration and attenuation.

After 5 years of annual monitoring, as specified in the NCP (EPA, 1990a), trends in contaminant distribution would be analyzed and compared to model predictions to evaluate the effectiveness of this option and to determine whether the plume is expanding, shrinking, or has reached a dynamic steady-state equilibrium. It may be possible to reduce the monitoring frequency at that time.

Effectiveness: Natural attenuation (intrinsic remediation) of VOCs has been thoroughly documented in the literature. Natural attenuation has been implemented in many instances, particularly where source control/removal has been accomplished and where potential receptors face no immediate risk of exposure.

Implementability: Natural attenuation is rapidly gaining regulatory acceptance as an alternative for addressing groundwater contamination. There are no physical barriers to implementing this option at Tinker AFB. With appropriate education (e.g., meetings, presentations, or press releases), the public should be receptive to natural attenuation.

Costs: The costs for implementing natural attenuation generally are low relative to engineered groundwater remediation technologies. If monitoring must continue for a long period, however, the present-worth costs of natural attenuation with monitoring may not appear significantly lower than those for capital-intensive or maintenance-intensive options operating within a shorter time frame.

This alternative will be retained for detailed evaluation.

5.2.2.3 Alternative S-3. Upgrade Existing Extraction System with Treatment Options

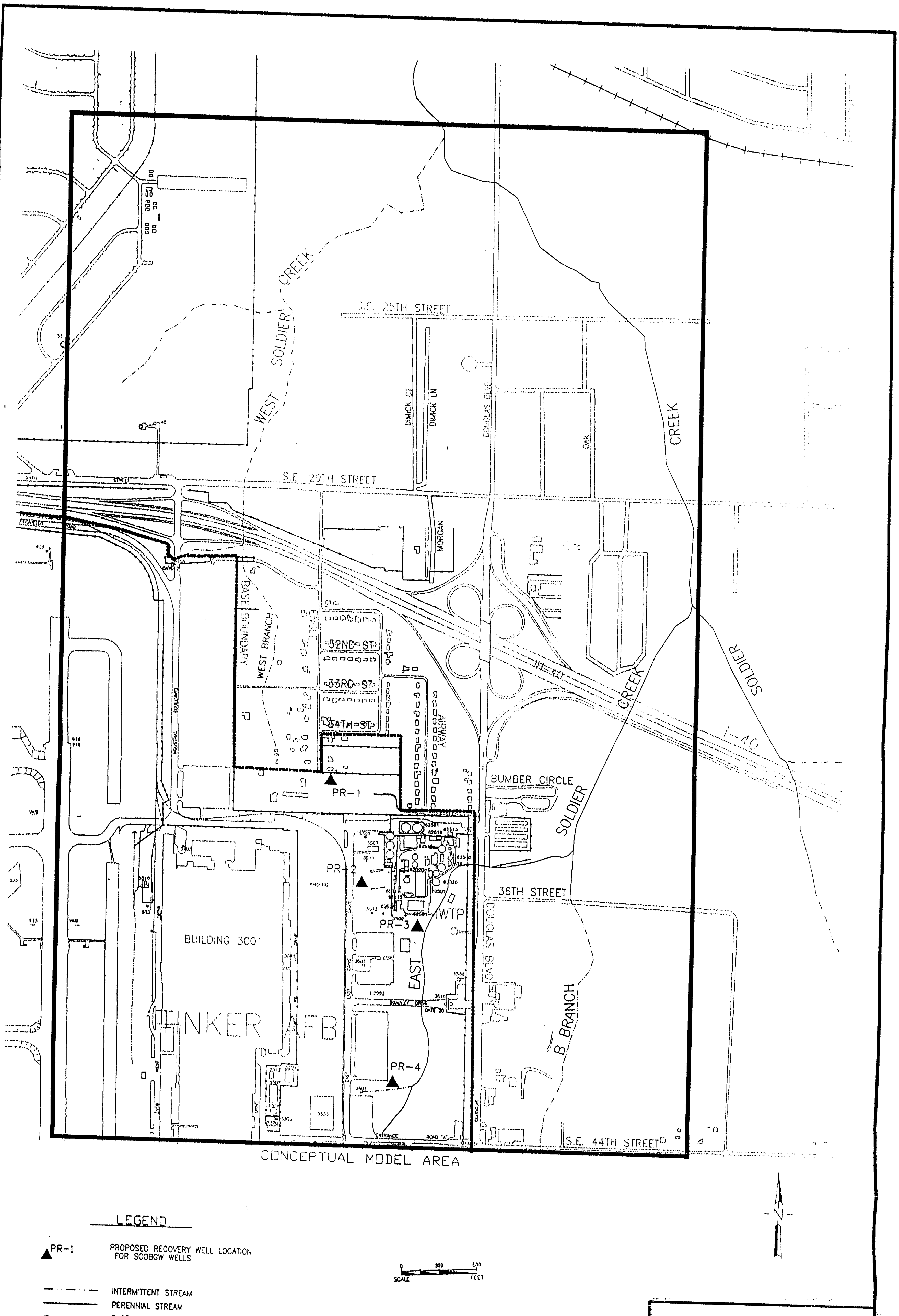
This alternative includes an upgrade of the current extraction system, four treatment options, and two disposal options. Each of the options will be evaluated separately and combined to form the best pump-and-treat alternative. The final recommendation will include at a minimum one option from each column:

A Groundwater Extraction	B Treatment Options	C Disposal Option
New well field	• Upgrade existing GWTP • Pretreat for vinyl chloride • Treatment System • IWTP	Industrial reuse POTW

Alternative S-3, upgrade of the existing extraction system, includes the installation of four new cluster wells (i.e., well field) for recovering groundwater north and east of the current extraction system at Building 3001. A well field consists of several wells spaced closely together which are pumped to contain the plume and recover the groundwater. The new well field will increase the capture zone of the existing system and supply approximately 45 gpm of contaminated groundwater to an appropriate treatment system (see Figure 5.1 for proposed recovery well locations and Appendix C for computer simulations). Water from the new recovery wells will be pumped through a 2½-inch diameter, double-walled pipe to an equilibrium tank. Treatment options (column B) evaluated under this alternative are:

- S-3-1 Upgrade of existing groundwater treatment plant (GWTP);
- S-3-2 Pretreatment for vinyl chloride;
- S-3-3 New treatment system; and
- S-3-4 IWTP treatment.

Treatment option S-3-1 includes the upgrade of the existing treatment system for Building 3001 which remediates groundwater contaminated with VOCs and hexavalent chromium (which exceeds MCLs) by use of a packed column air stripper with carbon adsorption system (CAS) as off-gas treatment, and a chemical reduction and precipitation system for treatment of chromium. The remaining organics and metals are removed by a fine filtration process. A general process flow diagram of the existing GWTP is shown in Figure 5.2. The upgrade of the existing GWTP option includes additional groundwater storage capacity and ancillary equipment upgrades. The existing GWTP, with minor equipment upgrades, has the capacity to treat the additional groundwater expected to be treated with this alternative. Currently, the GWTP treats an average flow of 150 gpm.



SOURCE: BLACK AND VEATCH, 1993b.

Figure 5.1

Proposed Recovery Well Location Map

Tinker AFB, Oklahoma

EXTWELL 4/10/96

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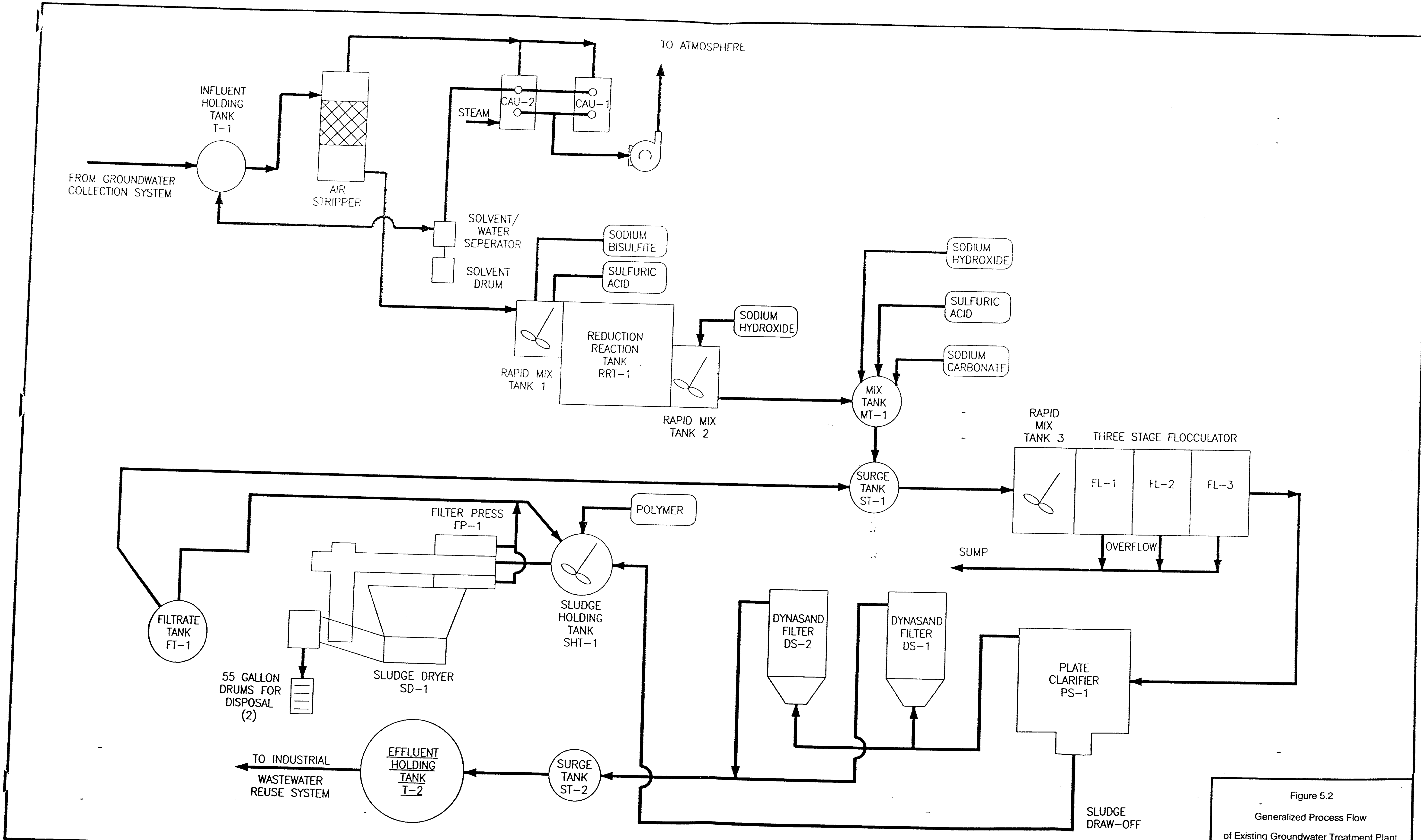

Figure 5.2
Generalized Process Flow
of Existing Groundwater Treatment Plant
Tinker AFB, Oklahoma

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The influent to the GWTP would increase to 195 gpm with the predicted increase of 46.3 gpm from the proposed new well field (Appendix C). An optimization study (Parsons ES, 1996c) recommended a 60 gpm flow reduction to the GWTP from the Building 3001 groundwater extraction system. The adoption of this 60 gpm reduction and the proposed 41.3 gpm addition would decrease the GWTP influent from 150 gpm to 135 gpm.

Treatment option S-3-2 includes the installation of a new pretreatment system which includes a new air stripping unit for removal and destruction of vinyl chloride from the recovered groundwater. The pretreated water is then routed to the existing upgraded GWTP for metals treatment.

The new vinyl chloride air stripping unit is a low profile plate air stripper system with off-gas treatment designed specifically for vinyl chloride remediation. The unit will handle a maximum of 100 gpm and can also strip other VOCs such as *cis*-1,2-DCE and TCE. The vinyl chloride impacted groundwater pretreatment system includes the following principal components: equalization tank, low profile air stripper, and a catalytic oxidizer. The catalytic oxidization treatment of the stripper off-gas would provide near-complete (95+%) destruction of vinyl chloride. The catalytic oxidizer would utilize natural gas as a supplemental fuel. The extracted water would then be sent to the existing groundwater treatment unit for removal of metals. The annual vinyl chloride emissions resulting from continuous operation of the unit is estimated to be 6.7 lb/yr for a flow of 45 gpm, with a worst case concentration of vinyl chloride at 610 μg/L (well 1-50AR, Table 2.3). The metals and other chlorinated solvent treatment consists of utilizing the existing treatment system.

Treatment option S-3-3 includes the installation of a new treatment system designed for treating the recovered groundwater from the upgraded extraction system. The new unit would include an ultrastrip low profile air stripper with CAS off-gas treatment, system housing, and various ancillary equipment necessary to handle the recovered groundwater.

Treatment option S-3-4 provides for treatment of the recovered groundwater by the existing IWTP. The IWTP could handle the additional water flow and contaminants of concern, but has no off-gas treatment system. Control of VOC off-gas is not cost efficient for the current IWTP. A general process flow diagram of the existing IWTP is shown in Figure 5.3.

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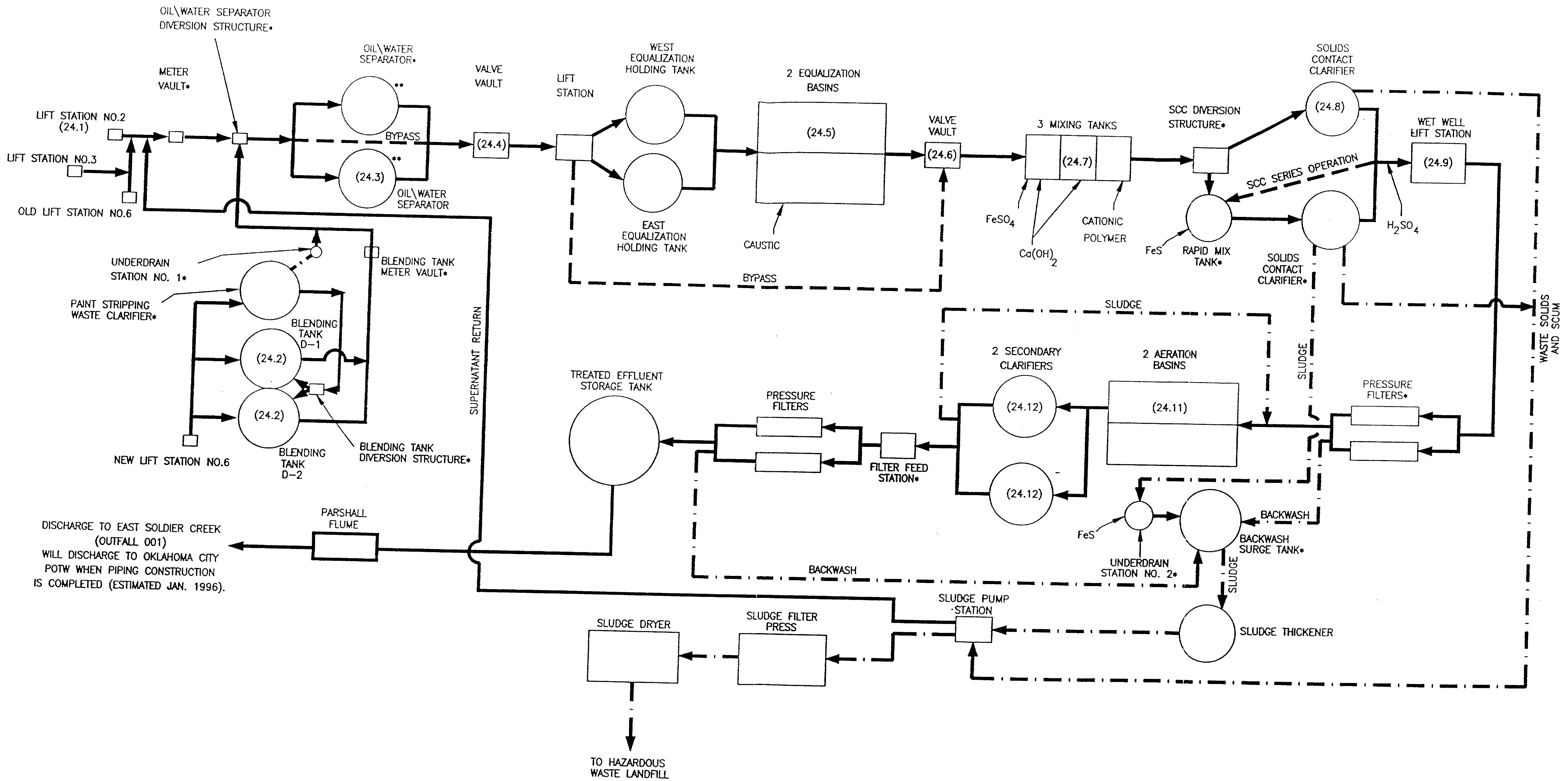

EFFLUENT PATH

SLUDGE/BACKWASH PATH

ALTERNATE PATH

* CONSTRUCTED IN 1994

** OIL AND SLUDGE TO HAZARDOUS WASTE LANDFILL.

NUMBER IN BRACKET ( ) IS SWMU IDENTIFIER.

Figure 5.3
Generalized Process Flow Diagram for IWTP

Tinker AFB, Oklahoma

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There are two disposal options for the treated water, discharge to the industrial reuse system (D-1) or discharge to the local POTW through the IWTP outfall (D-2). Both options have discharge concentration limits and monitoring requirements.

The effect of the remediation on the solvent plume will be monitored by annual sampling of the existing wells which best represent the plume area.

Effectiveness: Overall protection of human health and the environment would be provided by this alternative by collection and treatment of the groundwater plume. The chemical-specific ARARs will be met as the contaminated water is removed and treated. Other location and action-specific ARARS will also be complied with during the construction and maintenance phases of the remedial action. Treatment option S-3-2 is the only option that specifically addresses potential air emissions associated with vinyl chloride.

Implementability: The recovery, treatment, and monitoring option identified in this alternative is technically implementable and has shown to be effective at many other sites. The materials and services needed to implement this option are readily available.

Costs: Alternative S-3 will include costs for the installation of four new cluster wells. In addition, costs for the treatment options identified vary significantly. Treatment option S-3-1 and S-3-4 are the least expensive options identified. Treatment options S-3-2 and S-3-3 have higher costs than the other options identified. Both disposal options have relatively low costs.

For the purposes of the FS, the alternative S-3 treatment options that will undergo detailed evaluation include: S-3-1, S-3-2, S-3-4 with both disposal options considered for S-3-1 and S-3-2. Because the existing IWTP treatment system discharges to the POTW, only the POTW disposal option will be evaluated for treatment option S-3-4. Treatment option S-3-3 is cost prohibitive; therefore, it will not be included in a detailed evaluation.

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SECTION 6

DETAILED ANALYSIS OF ALTERNATIVES

6.1 INTRODUCTION

The U.S. Environmental Protection Agency established nine criteria in the National Contingency Plan to be used in evaluating each remedial action alternative for compliance with the statutory requirements (EPA, 1990a). Based on EPA guidelines, a detailed analysis follows for each alternative developed in the initial screening of alternatives providing a common basis to determine the best alternative for each site. These evaluation criteria are presented in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988b). The nine criteria are divided into three groups as follows:

Threshold criteria:

- Overall protection of human health and the environment, and
- Compliance with applicable or relevant and appropriate requirements (ARARs)

Primary balancing criteria:

- Long-term effectiveness and permanence,
- Reduction of mobility, toxicity, and volume (MTV),
- Short-term effectiveness,
- Implementability, and
- Cost

Modifying criteria:

- State acceptance,
- Community acceptance.

The selected remedial action alternative must meet the threshold criteria. The balancing criteria are used to distinguish among those alternatives which meet the threshold criteria. The modifying criteria are evaluated after the FS is presented to the regulatory agencies and the public. Each criterion is described in more detail below.

6.1.1 Overall Protection of Human Health and the Environment

This evaluation criterion addresses whether the proposed remedial action alternative is protective of human health and the environment given the specific site characteristics. This evaluation is based on a compilation of the other, more detailed, evaluation criteria. This standard must be achieved by the selected remedial action.

6.1.2 Compliance with ARARs

The evaluation of alternatives under this criterion is used to determine whether each alternative complies with federal and state ARARs and other appropriate criteria, advisories, and guidances. For each alternative considered at a site, the discussion includes consideration of four categories: chemical-specific ARARs, location-specific ARARs, action-specific ARARs, and other available guidance. When an ARAR is not met, the basis for justifying one of the six waivers allowed under CERCLA must be discussed.

CERCLA contains provisions to waive the requirements of ARARs in six circumstances:

1. The selected action is an interim remedy and the final remedy will attain the ARAR.
2. Compliance with the ARAR will result in a greater risk to human health and the environment.
3. Compliance with the ARAR is technically impractical.
4. The alternative will use another method to attain an equivalent standard.
5. The ARAR is a state requirement which has not been consistently applied in similar circumstances.
6. Compliance with the ARAR does not provide a balance between protection of human health and the environment and availability of funds for response action at other sites. This waiver may only be used for section 104 Superfund financed remedial actions.

6.1.3 Long-term Effectiveness and Permanence

This criterion addresses the risk remaining after completion of a remedial action. The extent and effectiveness of the controls required to manage the residual risk are the focuses of this evaluation. Both the magnitude of residual risk and the reliability of available controls are considered.

6.1.4 Reduction of Mobility, Toxicity, or Volume

The statutory preference for selecting remedial actions that reduce MTV of contaminants is addressed in this criterion. Preference is given to those remedies which reduce the mass of contamination or irreversibly reduce the mobility of a contaminant or render the contaminant non-toxic at a site.

6.1.5 Short-term Effectiveness

This evaluation criterion addresses the effects of the alternative during the implementation and construction phase. Protection of the on-site workers and the general community are considered. Potential environmental impacts and the time needed for remedial response are also considered.

6.1.6 Implementability

The evaluation of alternatives under this criterion addresses the technical and administrative feasibility of implementing the alternative. Consideration will be given to how reliable the technology is, the ability to monitor the remedy, and the availability of equipment.

6.1.7 Cost

This evaluation criteria includes both capital costs and operation and maintenance (O&M) costs. The capital cost estimates include both direct (construction) and indirect (nonconstruction and overhead) costs. Indirect costs are estimated as a percentage of the direct capital. A 25 percent contingency is included in the capital cost estimate. This amount is intended to account for costs not otherwise accounted for in the conceptual design such as costs for bid and scope contingencies. The costs are based upon best estimates of the volume of contaminated groundwater, as determined during the RI, and standard equipment designs. The cost estimates have an accuracy of -30 percent to +50 percent as recommended in the EPA RI/FS guidance (EPA, 1988b). As recommended by EPA guidance, a discount factor of 5 percent and an operational period of 30 years are used for the determination of present worth costs for cost evaluations. Detailed information for the cost estimates is located in Appendix B.

6.2 REMEDIAL ACTION OBJECTIVES

The results of the site investigation for the IWTP/SCOBGW OUs indicate that groundwater was the primary contaminated media of concern. Soils were not found to be significantly contaminated and thus are not considered an operable unit. Remediation of contaminated groundwater is the focus of this feasibility study. The remedial action objectives for the IWTP/SCOBGW OUs are as follows:

1. Minimize human health risk from potential ingestion of contaminated groundwater.
2. Minimize environmental risks from potential exposure to groundwater.
3. Minimize potential short-term and long-term exposure resulting from remedial activities.

The exposure pathways used to develop the baseline risk assessment assumed the groundwater would be used by the public as a primary drinking water source. However, this scenario is unlikely to occur at the base due to the low recharge rates to wells from the USZ, LSZ, and the ample availability of city water. A detailed discussion of the risk assessment is presented in the draft risk assessment report (Parsons ES, 2000). The unacceptable risk, by assuming that people will drink the contaminated groundwater, associated with vinyl chloride will be used as PRG for the south of the groundwater divides in the IWTP/SCOBGW OUs. Section 3 addresses the PRGs for the feasibility study. The PRGs will be used as the preliminary standard for the long-term groundwater cleanup level and as a preliminary treatment standard for groundwater which is pumped, treated, and discharged. The final remedial action target concentrations may be greater than the PRGs presented here. The actual discharge concentration limit will be determined based on operating permits required to discharge to the city POTW or to an industrial reuse system.

6.3 DETAILED ALTERNATIVE EVALUATIONS

The following sections discuss the alternatives as they relate to the assessment criteria. These alternatives were previously developed in Section 4. Table 6.1 presents a summary of the evaluation criteria assessments of the alternatives presented in greater detail in Tables 6.2A through 6.2C.

Alternative N-1. No Action

Overall protection of human health and the environment is not necessarily met by this alternative. Current data indicate that risks north of the divide are due to concentrations of the naturally occurring thallium which will not be remediated. With this option, it will not be known if nearby populations or the environment are exposed to contaminated groundwater in the future under the no-action alternative. Measures to protect people and the environment against exposure to potentially contaminated groundwater will not be taken.

Table 6.1 Summary of Alternative Evaluation Criteria Assessment

Alternative Description	Applicable Sites	Alternative ID	Location of Criteria Assessment
No Action	Areas north and south of groundwater divide	N1 and S1	Table 6.2A
Limited Action	Areas north and south of groundwater divide	N2 and S2	Table 6.2B
Extraction and treatment of groundwater	Area south of groundwater divide	S3	Table 6.2C

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Table 6.2A Detailed Alternative Evaluation Criteria Assessment
No Action Alternative (N1 and S1)

Evaluation Criteria	Assessment Factors	General Comments
Overall protection of human health and the environment	How risks are eliminated, reduced, or controlled	North of groundwater flow boundary - Does not reduce perceived short-term risks. Over a long time period, risk may reduce, if contaminant levels naturally attenuate. Monitoring to track contaminants will not be conducted. Naturally occurring thallium will most likely not attenuate. Presently, no endangered species have been identified at the site. South - Building 3001 recovery system would limit the migration of contaminant plume to be on base and possibly capture the contaminants. Some contamination would also naturally attenuate.
Compliance with ARARs	Chemical specific	Complies with ARARs north of divide. Does not comply with chemical criteria south of divide where vinyl chloride in groundwater are above EPA risk level and PCE, TCE, and *cis*-1,2-DCE above the proposed ACLs.
	Location specific	Complies with requirements to protect endangered species, antiquities, and historical sites.
	Action specific	No action-specific ARARs as there are no remedial actions.
Long-term effectiveness and permanence	Magnitude of residual risk and reliability of controls	Residual risk remains until contaminants are naturally reduced.
Reduction of toxicity, mobility, and volume	Expected reductions in toxicity, mobility, and volume	South of groundwater flow boundary - Dilution and degradation will occur over time eventually reducing toxicity for those contaminants whose source has been eliminated. Volume of contaminated water may increase as plume migrates and disperses and then decreases by natural attenuation. The time required for natural attenuation cannot be ascertained at this time. The Building 3001 extraction system will slowly reduce MTV. Again, naturally occurring metals will not naturally attenuate.
Short-term effectiveness	Environmental impacts	
	Worker and community protection	No short-term risks, because no exposure pathways are complete.
Implementability	Ability to construct and maintain	Not applicable.
	Ability to monitor effectively	No monitoring will be done.

Table 6.2B Detailed Alternative Evaluation Criteria Assessment
Limited Action Alternative (N2 and S2)

Evaluation Criteria	Assessment Factors	General Comments
Overall protection of human health and the environment	How risks are eliminated, reduced, or controlled	Monitoring will track migration of plume. Presently, no endangered species have been identified at the site; the alternative is expected to be protective of those that may be found in the future.
Compliance with ARARs	Chemical specific	ARARs would be met over an extended time period by natural attenuation in the south. Complies with ARARs north of the divide.
	Location specific	Complies with preservation of antiquities and historical sites requirements.
	Action specific	Complies with monitoring requirements. No known archeological findings at the site. The alternative is not expected to threaten any that may be found in the future.
Long-term effectiveness and permanence	Magnitude of residual risk	Residual risk is low.
	Adequacy and reliability of controls	Monitoring would indicate rising contaminant levels and exceedance of acceptable risk levels.
Reduction of toxicity mobility and volume	Degree of expected reductions	South - Dilution and degradation will occur over time eventually reducing toxicity. Volume of contaminated water may increase as plume migrates and disperses or decreases by natural attenuation. The time required for natural attenuation cannot be ascertained at this time. The Building 3001 extraction system will reduce MTV of the plume south of the groundwater divide.
Short-term effectiveness	Time until remedial action objectives are achieved	Annual groundwater monitoring data will be evaluated every 5 years, as required by the NCP.
	Community and worker protection	No short-term risks are expected.
	Environmental impacts.	No short-term risks are expected because no extensive construction will take place.
Implementability	Ability to construct and operate technology	Monitoring wells are already in place.
	Coordination with other agencies	None.

Table 6.2C Detailed Alternative Evaluation Criteria Assessment
Extraction and Treatment of Groundwater Alternative (S3)

Evaluation Criteria	Assessment Factors	General Comments
Overall protectiveness of human health and the environment	How risks are eliminated, reduced, or controlled	Future risks to human health from groundwater contaminants would be minimized by prevention of plume migration, onsite recovery and treatment of contaminated groundwater; and performance of groundwater sampling to monitor contaminant levels. Presently, no endangered species have been identified at the site; the alternative is expected to be protective of those that may be found in the future.
Compliance with ARARs	Chemical specific	ARARs will be met by the enhanced pumping and treatment and also over an extended time period by natural attenuation.
	Location specific	Complies with preservation of endangered species, antiquities, and historical sites requirements.
	Action specific	Complies with monitoring requirements. No known archeological sites at the site. The alternative is not expected to threaten any that may be found in the future.
Long-term effectiveness	Magnitude of residential risk	The groundwater recovery and treatment system would reduce contaminant levels faster than the Building 3001 P&T system alone. Residual risk would be low.
	Adequacy of controls	The groundwater recovery system would adequately contain groundwater onsite. Groundwater monitoring would serve as an adequate control.
	Reliability of controls	Groundwater recovery and treatment and groundwater monitoring are effective and reliable controls.
Reduction of toxicity, mobility, or volume	Amount destroyed or treated	Contaminated concentrations in the groundwater would be reduced via recovery and treatment. After five years, based on computer simulations (Appendix D), the extraction system will pump mostly clean water. The cleanup (capture) efficiency will drop significantly.
	Irreversible treatment	Groundwater contaminant treatment is irreversible.

Table 6.2C, continued

Evaluation Criteria	Assessment Factors	General Comments
	Type and quantity of residuals remaining after treatment	Contaminants in groundwater would be recovered and treated. Sludge containing high levels of metals will require off-site disposal as well as recovered solvent.
Short-term effectiveness	Time until action is complete	Remedial actions, such as installation of the recovery and treatment system, would be accomplished in a short time period. Groundwater recovery and treatment would be accomplished over five years based on computer simulations (see text).
	Community and worker protection	Low short-term risks to the community and workers are anticipated.
	Environmental impacts	Low short-term risks to the environment are expected. No extensive construction/earth-movement activities are included in this alternative.
Implementability	Ability to construct and operate	Remedial actions easy to implement and maintain by upgrading existing GWTP.
	Reliability of action	Groundwater recovery will reliably contain contamination plume, and treatment will reduce the contaminants' volume, and toxicity. Groundwater monitoring is expected to be a reliable measure for assessing contaminated groundwater.
	Ability to monitor effectively	Easy to monitor groundwater contaminant levels and monitor effluent discharge levels.
	Administrative feasibility	CERCLA/SARA cites a preference for permanent remedies to reduce MTV.
	Availability of services and materials	All equipment and services readily available.

The chemical-specific ARARs are met in the short term for this alternative because the concentrations of the contaminants of concern listed in Table 2.6, other than thallium, do not exceed acceptable risk levels. Over the long-term, the concentrations of these contaminants in the groundwater may naturally be reduced. However, there will be no monitoring to confirm this.

The long-term effectiveness criteria is not met by this alternative. Adequate and reliable controls will not be used to protect against potential future use of the groundwater.

The no action alternative does not reduce the mobility, toxicity, or volume of the contaminants. The volume of the contaminated groundwater may actually increase but become more diluted as the contaminants migrate through the aquifer medium.

The short-term risks to workers and the community are eliminated because no construction activities will take place. There are no environmental impacts from implementation of this plan.

The alternative is easily implemented. There are no capital or operating costs associated with the no-action alternative. However, there may be unknown liability costs.

Alternative N-2. Limited Action (Institutional Controls and Continued Monitoring)

Overall protection of human health and the environment will be provided under this alternative. Annual groundwater monitoring will track contaminant movement, signaling the base to possibly increasing contaminant levels.

The long-term effectiveness criterion will only be met if contaminant monitoring provides sufficient notice of contaminant concentration increase so that additional remedial actions can be taken if needed.

There are minimal risks of exposure while collecting groundwater samples. There are no adverse environmental impacts from the implementation of this alternative.

This alternative is easily implemented. The existing wells can be used to collect samples for analysis to track the plume. The high solids content and low flow rates will naturally discourage use of the water in the shallow aquifer.

The capital cost estimated for this alternative is $5,000. The estimate of the annual O&M cost is $25,000, and the present worth cost for a 30-year period is $385,000. The total cost, present worth plus capital cost, is $392,000. Details of the cost calculations are in Appendix B.

Alternative S-1. No Action

Overall protection of human health and the environment is not necessarily met by this alternative. Measures will not be taken to ensure that on-base workers and the environment are not exposed to contaminated groundwater because the plume is approximately 20 feet or more below ground surface, and currently the base is not using the shallow groundwater.

The chemical-specific ARARs are not met in the immediate future for this alternative because contaminant concentrations in the groundwater exceed the MCLs. However, the groundwater contamination is within the capture zone of Building 3001 pump-and-treat system and natural degradation of the contaminants in the groundwater has occurred. The half-lives of TCE and DCE are estimated at 4.5 and 79 years, respectively (Howard et al., 1991). Plume monitoring will not be used to evaluate if natural attenuation reduces contaminant concentrations below the MCLs.

The long term effectiveness criteria is not met. Reliable controls will not be in place to ensure adequate protection of human health and the environment. The long-term risks are not reduced because the contaminated groundwater will remain for an extended time period without monitoring to support the presumption that the plume will not substantially migrate. The very long term risks may eventually be reduced through natural attenuation of the contaminant plume, and through eventual plume capture by the extraction system at Building 3001.

The no action alternative does not reduce the MTV of the contaminants. The volume of the contaminated groundwater may actually increase as the contaminants migrate throughout the aquifer and then eventually decrease by natural attenuation.

The short-term risks to workers and the community are eliminated because no construction will take place onsite. There are no environmental impacts from implementation of this plan.

The alternative is implemented. There are no capital or operating costs associated with this alternative.

Alternative S-2. Natural Attenuation with Monitoring and Institutional Controls

This alternative includes institutional controls and monitoring; however additional sampling and analysis (and possibly modeling) will be added to demonstrate the effectiveness of natural attenuation processes. There is already evidence of the effectiveness of these processes; for example, *cis*-1,2-DCE has been detected at the site. It is the most common isomer resulting from the anaerobic biodegradation of TCE, whereas the *trans*-1,2-DCE isomer is more common as an industrial solvent (Little, 1985). In addition, the presence of vinyl chloride is a further indicator of continuing biodegradation, in this case the biodegradation of *cis*-1,2-DCE.

To further define and quantify the natural attenuation processes operating at the site, groundwater samples would be collected from about thirty wells within portions of the plume east and northeast of Building 3001 (away from the pump-and-treat system) and analyzed for contaminant and geochemical parameters. Sampling for hydrogeochemical parameters will give further insight to which processes are actually occurring and may also provide additional evidence that vinyl chloride is degrading. The presence of ethane in groundwater is a strong indication that vinyl chloride is biodegrading anaerobically and that the anaerobic biodegradation pathway is complete.

Overall protection of human health and the environment will be provided under this alternative. Discontinued use of the base water-supply wells in the area eliminate the ingestion exposure pathway. Additional controls, including limiting site access, may also be used to eliminate other potential pathways. Long-term monitoring will allow monitoring of the plume extent and concentrations to ensure that natural attenuation is limiting further migration and will not allow completion of exposure pathways.

Currently, vinyl chloride concentration in groundwater exceeds its MCL. However, vinyl chloride concentrations will decrease over the long term as natural attenuation processes act to reduce contaminant concentrations. Biodegradation, dispersion, dilution, volatilization, and sorption will continuously act to reduce the volume of groundwater contaminated with TCE, *cis*-1,2-DCE, and VC concentrations. Ultimately, VC concentrations will be reduced to levels below ARARs or below those that contribute to unacceptable risk. It should be noted that natural attenuation of VC is significantly slower than for petroleum hydrocarbons, which can be used by microbes as a primary growth substrate.

The long-term effectiveness criterion should be met by this alternative. Discontinued use of surrounding private supply wells by the Oklahoma County plugging and abandonment program and groundwater monitoring have been providing reliable controls to prevent exposure. Long-term risks will be reduced through natural attenuation of groundwater contaminants. Ongoing Building 3001 extraction of site groundwater will help limit migration of the contaminant plume. Site reviews could be conducted every year using long-term monitoring data. The purpose of these reviews would be to (1) evaluate the extent of contamination, (2) assess contaminant migration and attenuation through time, (3) document the effectiveness of institutional controls, and (4) reevaluate the need for additional remedial actions.

Mobility of groundwater contaminants will not be altered. After contaminant migration from soil to groundwater has ceased, toxicity of contaminants will gradually be reduced through natural attenuation of the plume and the Building 3001 P&T system. If the groundwater plume has not reached a dynamic steady state, growth of the plume will initially increase the volume of contaminated groundwater; however, concentrations will continue to decrease, eventually resulting in a decreased volume of contaminated water.

Any short-term risks to base workers contacting the plume during the implementation of this alternative can be controlled to within acceptable levels by using engineering controls and implementing the remedial actions in accordance with a health and safety plan conforming to OSHA rules. There are minimal risks of exposure by following the health and safety plan while collecting groundwater samples. There are no adverse long-term environmental impacts from implementation of this alternative.

This alternative is easily implemented. Existing monitoring wells can be used for groundwater sampling to track plume migration and degradation. An alternate source of drinking water is available from surrounding municipal supplies. Public education on this alternative would be developed to inform base personnel, regulators, and local residents of the scientific principles underlying natural attenuation, as well as the benefits and limitations of this alternative.

The costs are estimated under the assumption that 30 years of annual monitoring will be necessary and that a natural attenuation study will be conducted during the first year of monitoring. While it may be possible to reduce the sampling frequency, it is also possible that sampling may need to extend beyond 30 years. Thus, this estimate represents a compromise between the endpoints of the likely sampling time frame. The capital cost estimated for this alternative is $5,000. The estimate of the annual O&M cost is $27,000, and the present worth costs for a 30-year period is $416,000. The total cost, present worth plus capital cost, is $423,000. Details of the cost calculations are in Appendix B.

Alternative S-3. Upgrade Existing Extraction and Treatment Systems

Overall protection of human health and the environment will be provided by this alternative by interception and treatment of the groundwater plume.

The chemical-specific ARARs will be met within 5 years (see Appendix C) as the contaminated water is removed and treated. Other location and action-specific ARARs will also be complied with during the construction and maintenance phases of the remedial action.

Annual groundwater sampling and analysis will monitor the effectiveness of the ongoing treatment. The treatment systems considered as part of this option all provide irreversible treatment, i.e., contaminants such as TCE and DCE will be destroyed or removed permanently from the groundwater. Vinyl chloride emissions will not be effectively controlled by treatment options S-3-1 and S-3-4. Treatment option S-3-2 is the only option identified that provides for vinyl chloride emission control. The state of Oklahoma air quality regulations provides an exemption from control of hazardous and toxic air contaminant emissions (OAC title 252 chapter 100 subchapter 41 - Control of Emissions of Hazardous and Toxic Air Contaminants) for *de minimus* levels. Vinyl chloride is identified as a category A (highly toxic) compound, and as such, *de minimus* levels are 0.57 lb/hr and 1,200 lb/yr. Calculated worst case emissions of vinyl chloride are 0.014 lb/hr. The assumptions for calculating the worst case vinyl chloride emissions are 45 gal/min groundwater flow (Appendix C) with 610 ppb vinyl chloride concentration (Table 2.3, well 1-50AR), 100 percent removal efficiency of vinyl chloride by the air stripper and no removal efficiency from the existing CAS. Therefore, treatment options associated with S-3 meet the statute of Oklahoma air quality requirements.

The toxicity of the contaminants will be reduced through natural dilution, degradation, or through active treatment of the groundwater. The volume of the contaminated groundwater will be reduced by removal and treatment of the plume. Mobility of the contaminants in the aquifer are not directly addressed by this alternative.

Short-term risks to workers and the community are not expected. Potential exposure risk during construction or treatment activities will be reduced using engineering controls.

The estimated capital and annual O&M costs for the new well field installation, which includes a double contained piping system with leak detection, are $265,000 and $55,000, respectively. The estimated total present worth for the upgrading of the extraction system (i.e., installation of new well system, alternative S-3) for a 30-year period at a 5 percent interest rate is $1,111,000. The estimated total present worth costs for each of the three treatment options are: upgrading existing GWTP, $935,000 (alternative S-3-1); pretreatment of vinyl chloride with upgrades to existing GWTP, $1,626,000 (alternative S-3-2); and IWTP treatment $921,000 (alternative S-3-4, Appendix B). The pretreatment of vinyl chloride option has the greatest capital costs.

The two treatment options that are in current operation (i.e., GWTP and IWTP) have much lower capital costs. Estimated cost of treatment by the IWTP is approximately \$1.23 per 1,000 gallons of water treated. A total of 24 million gallons of recovered groundwater is expected to be treated. The costs associated with the disposal options, industrial reuse (D-1) and POTW (D-2), were considered for groundwater disposal. The industrial reuse disposal option is currently adequate for the expected increase in treated water to be handled. Therefore, no additional costs are expected for disposal option D-1. The estimated total capital costs and annual O&M costs for the POTW disposal options are \$3,000 and \$60,000, respectively. The total present worth costs including the capital costs are \$928,000.

A computer simulation (Appendix C) was performed using Figure 5.1 preliminary well field layout. The simulation indicated that layer 3 wells could not sustain pumping at a rate above 0.02 gpm except at PR-3 locations. The recommended configuration is to pump layers 5 and 7 only at a rate of 10 gpm/well for well cluster PR-1 (layer 7), -2 (layers 5 and 7), and -3 (layers 5 and 7). PR-2, layer 5 wells, has to be set at 1.3 gpm with a total pumpage of 45 gpm. Nonetheless, at this recommended well field and pumpage, after 5 years operation, a significant amount of noncontaminated water will be captured and treated.

Thus, the O&M plan should include a quarterly monitoring program of these PR-series wells on pumping rate, water level, and contaminant concentrations. When the contaminants decrease below MCLs, the extraction pump will be shut down but not abandoned. Because it is documented that the diffusion of the adsorbed contaminants by the soils may increase the groundwater concentration after the pumping is terminated. The pumping will be resumed when the concentration is above MCLs and also shows an increasing trend.

Moreover, particle tracking simulations indicated that contaminants will be captured by the Building 3001 P&T system even without the PR-series extraction wells. The interpretation of the Building 3001 P&T well field optimization report (Parsons ES, 1996c) also corroborates that the IWTP/SCOBGW OUs plume would be captured by the Building 3001 P&T system.

Summary

The remedial alternatives for the area north of the groundwater divide generally compare favorably with the evaluation criteria. Although alternative N-1, no action, does not necessarily meet the criteria for overall protection of human health and the environment, it does comply with ARARs. However, the only contaminant which posed unacceptable health risks and exceeding MCLs was thallium, a naturally occurring trace metal not associated with any past or present uses at Tinker AFB.

A summary of the estimated costs is presented in Table 6.3. The least cost alternative that meets all evaluation criteria is N-1, no action for the area north of the groundwater divide.

The least cost remedial alternative that meets all evaluation criteria for the area south of the groundwater divide includes upgrading the existing Building 3001 groundwater pump-and-treat system (S-3-1). The treated waters would be routed to the industrial wastewater reuse system also currently in operation for Building 3001.

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Table 6.3 Summary of Costs for Remedial Alternatives

	No Action		Limited Action		Groundwater Extraction System	Groundwater Treatment Upgrade GWTP	Groundwater Treatment Pretreat for VC	Groundwater Treatment IWTP	Groundwater Disposal Industrial Reuse	Groundwater Disposal POTW
	N-1	S-1	N-2	S-2	S-3	S-3-1	S-3-2	S-3-4	D-1	D-2
Capital	0	0	2	2	265	166	350	14	0	5
Annual O&M	0	0	25	27	55	50	83	59	0	60
Present Worth	0	0	385	416	846	769	1,076	907	0	863
Total (capitol plus present worth)	0	0	387	418	1,111	935	1,626	921	0	928

1. All numbers are reported in $1,000.

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SECTION 7

CONCLUSIONS AND RECOMMENDATIONS

The RI/FS guidance (EPA, 1988c) sets RAOs for groundwater to include: (1) human health, prevent ingestion of water having contaminants in excess of MCLs and a total cancer risk of greater than 10^{-4} to 10^{-6} or reference dose for noncarcinogen, and (2) environmental protection, restore aquifer to a certain concentration. Since both on- and off-base people are prevented from drinking groundwater, RAOs for human health have been achieved. For the second RAO, environmental protection, the aquifer will be restored to PRGs derived from risk assessment.

Each of the alternatives identified for the area north of the groundwater divide involves leaving groundwater in place while monitoring is ongoing. The groundwater in that area contains contaminants at concentrations less than the MCLs.

The alternatives identified for the area south of the groundwater divide also include leaving groundwater in place while monitoring is ongoing. In addition, the identified remedial alternatives for the groundwater south of the divide includes a pump-and-treat system using the existing GWTP. The GWTP is operating at 150 gpm and removes volatile organics and metals from groundwater extracted from the Building 3001 well field. By passing through the GWTP, additional groundwater extracted from the focused study area will not only be removed of vinyl chloride but also other contaminants.

The NCP requires all remedies which leave contaminants in place to be reevaluated every 5 years. The reevaluation could result in a recommendation for additional action, continued action, or a recommendation for no further action. The operations and maintenance cost calculations presented in this report assume a 30-year treatment and monitoring time frame.

North of the Groundwater Divide

The groundwater north of the identified divide contains low concentrations of metals and VOCs. However, these concentrations are well below MCLs, and metals concentrations are near background levels. The only contaminant which contributed to unacceptable risks was thallium, a compound not related to any past or present activities at Tinker AFB. The recommended action for the identified groundwater is alternative N-1, no action.

South of the Groundwater Divide

The groundwater south of the divide contains concentrations of vinyl chloride which contribute to unacceptable risks to human health. The existing GWTP is designed to treat solvents and metals. The recommended remedial action for remediation of the groundwater is alternative S-3-1, installation of a well field and upgrading the existing Building 3001 groundwater treatment plant with backup pump and equalization tank, with the treated effluent waters routed for industrial reuse. The cost is estimated to be \$2.05 million (\$1.111 + 0.935 + 0, Table 6.3). This alternative provides the most cost effective treatment system while alleviating public concerns of additional contamination from treatment activities. The existing wells will be sampled annually to monitor the progress of the treatment.

A potential alternative remedial action is treatment by the existing IWTP. However, this action is not recommended because of higher uncertainties associated with potential additional contamination of subsurface soils/groundwater by the lack of adequate secondary containment for treatment units at the IWTP.

Based on the groundwater modeling results (see Appendix C), any extraction wells installed east of East Drive would collect a majority of clean water after 5 years operation. Both Appendix C and the Building 3001 P&T system optimization study (PES, 1996c) indicate that the IWTP/SC plume is limited to on base and would be captured by the Building 3001 P&T system. Moreover, natural remediation of the solvent plumes has occurred. Granted, alternative S-2 may take a longer time to clean up the plume than the above-mentioned alternative. The cost for S-2 is estimated to be \$0.25 million vs. \$2.05 million for installation of a well field, upgrading the GWTP, and for industrial reuse.

However, by solely depending on the Building 3001 pump-and-treat system, one would envision a larger time frame. The system has to cleanup the Building 3001 plume first, then successively the IWTP/SCOBGW OU plume. Consequently, upgrading the existing extraction system and use of the GWTP with industrial reuse (alternative S-3-1/D-1) is recommended for the first 5 years. After the contaminant concentrations decrease below PRGs from the PR-series extraction wells, the pumping will cease and a quarterly groundwater quality monitoring program will be enacted to ensure the contaminant concentration remains less. The O&M cost would be for the first 5 years, not 30 years. The PR-series well pumps must be maintained after the first 5 years of operation in case the contaminant concentrations resurge upward. The maintenance cost would be relatively minimal compared to the O&M cost. The NCP requires a plume evaluation once every five years until it is determined unnecessary. Therefore, yearly monitoring of the plume is needed for the first 5 years.

Final Remedial Alternative

The recommended alternatives for areas north and south of the groundwater divide are preferred alternatives, not the final alternatives. The NCP prescribes that a proposed plan (PP) must be presented to the public for comment after the FS report. The PP will clearly state that Tinker AFB has identified a preferred alternative based on the available information but has not made a final decision on what remedy to implement. The final decision will be made in the ROD after Tinker AFB has taken into consideration the public's comments and any new and significant information presented.

According to EPA guidance (EPA, 1988a), the PP should clearly state that changes to the preferred/recommended alternative may be made if public comments or additional data indicate that modifications to the preferred alternative specified in this FS report would better achieve the cleanup goals for the site. At the conclusion of the public comment period, Tinker AFB will select a final alternative for adoption in the ROD. The preferred alternative will be reevaluated in light of any significant, new information that may have been received. As the result of the reevaluation, Tinker AFB may change a component of the final alternative or choose to implement a remedy other than the preferred alternative in the PP and thus, the FS report.

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SECTION 8

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APPENDIX A

OKLAHOMA STATE ARARS

A.1 CONTAMINANT-SPECIFIC ARARS

A.1.1 Air Quality

The ARARs apply if contaminants will be released into the atmosphere during construction or treatment.

- 27 A O.S. Supp. 1994, 2-5 et seq. (relevant and appropriate): Oklahoma Clean Air Act. Applicable if air concentrations are above the maximum allowable increase due to the remedial action.
- OAC 252:100 (relevant and appropriate): Oklahoma Air Pollution Control Rules. Implements the above act. Applicable if a new source and pollutant are sufficiently similar to regulated categories.

A.1.2 Water Quality

- 27 A O.S. Supp. 1994, 2-6-301 et seq. (relevant and appropriate): Oklahoma Water Supply Systems Act. Applicable if drinking water sources will be affected by the remedial action.
- OAC 252:625 (relevant and appropriate): Oklahoma Drinking Water Rules. Implements the above act.

Constituent	Level (mg/L)
Arsenic	0.050
Barium	1.020
Beryllium	NA
Chromium (total)	0.100
Thallium	NA
cis-1,2-Dichloroethene	0.07
Pentachlorophenol	0.001
Vinyl Chloride	0.002

- OAC 785:45 (relevant and appropriate): Oklahoma Water Quality Standards. Applicable if a discharge to surface water is included as part of the remedial action and if the surface water is or may be used as a water supply.

- 27 A O.S. Supp. 1994, 2-6-201 et seq. (relevant and appropriate): Oklahoma Pollutant Discharge Elimination System Act. Applicable if groundwater or surface water is treated and a point source discharge is generated.
- OAC 252:605 (relevant and appropriate): Oklahoma Pollution Remedies Rules. Implements the above act.
- OAC 785:45 (relevant and appropriate): Oklahoma Groundwater Quality Standards. Applicable if groundwater quality will be adversely affected by remedial actions.

Constituent	Level (mg/L)
Vinyl Chloride	0.0019
All other contaminants of concern	NA

A.2 ACTION-SPECIFIC ARARS

A.2.1 Solid Waste Management

- 27 A O.S. Supp. 1994, 2-10 et seq. (relevant and appropriate): Oklahoma Solid Waste Management Act. Applicable if solid waste unit or new non-hazardous waste landfill is constructed as part of the remedial action. Also, applicable if any solid or non-hazardous waste will be stored, transported, or disposed of as part of the remedial action.
- OAC 252:500 (relevant and appropriate): Oklahoma Solid Waste Management Rules. Implements the above act.

A.2.2 Hazardous Waste Management

- 27 A O.S. Supp. 1994, 2-7 et seq. (relevant and appropriate): Oklahoma Hazardous Waste Management Act. Applicable if groundwater quality may be adversely affected by the remedial action, e.g. leachate generated in stockpiles. Also, applicable if any RCRA hazardous waste will be treated, stored, or disposed of as part of the remedial action.
- OAC 252:200 (relevant and appropriate): Oklahoma Hazardous Waste Management Rules. Implements the above act. See criteria for 40 CFR parts 261/262, 264, 265, 268.

March 30, 2000

Jo Jean Mullen
HQ AFCEE\ERD
3207 North Road
Brooks AFB, TX 78235-5363

Reference: Contract F41624-94-D-8136
Delivery Order 0023, Groundwater Evaluation, Monitoring and Well Installation in Support of Compliance Activities at Camp Stanley Storage Activity, Texas
Technical Progress Report for Period 43 (February 1-29, 2000)
Performance and Cost Report for Period 43 (February 1-29, 2000) (CDRL C004)

Dear Ms. Mullen:

Parsons Engineering Science, Inc. (Parsons ES), is pleased to submit these period 43 monthly reports for the referenced delivery order. Enclosed is a hard copy of each report. Also, the package submitted to your office includes the electronic files on 3.5-inch diskette and two hard copies of the period 43 voucher.

Please call Jack Sullivan at (405) 732-9803, or me at (512) 719-6051 if you should have questions regarding any of this material.

Sincerely,

Susan V. Roberts
Project Manager

Enclosure

xc: Brian Murphy, CSSA Environmental Officer (1 copy)
AFCEE/ERS (2 copies)
AFCEE/ERSC (1 copy)
Delores Walker, HSC/PKVB (1 copy)
Carolyn Brown, DCMC (letter only)
J. Sullivan, Jr., Parsons ES-Oklahoma City (1 copy)
Project files (1 copy)

Appendix B

Cost Tables

Table 1. Cost Estimate for
Limited Action with Long-term Monitoring
Alternative N-2
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Post warning signs	$1,000	
Subtotal	$1,000	
Indirect capital		
Engineering (15%)	$150	
Contingency (25%)	$250	
Subtotal	$400	
Total capital		$2,000
Annual O&M:		
Groundwater sampling	$7,000	
Sample analysis	$8,000	
Annual monitoring report	$10,000	
Subtotal	$25,000	
Present worth O&M (5%, 30 yr.)		$385,000
Total present value (capital and present worth O&M)		$387,000

Table 2. Cost Estimate for
Limited Action with Long-term Monitoring
Alternative S-2
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Post warning signs	$1,000	
Subtotal	$1,000	
Indirect capital		
Engineering (15%)	$150	
Contingency (25%)	$250	
Subtotal	$400	
Total capital		$2,000
Annual O&M:		
Groundwater sampling	$8,000	
Sample analysis	$9,000	
Annual monitoring report	$10,000	
Subtotal	$27,000	
Present worth O&M (5%, 30 yr.)		$416,000
Total present value (capital and present worth O&M)		$418,000

Table 3. Cost Estimate for
Upgrade of Existing Groundwater Extraction System
Alternative S-3
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Complete new well installation (4 cluster wells)	$145,900	
Equipment supply (well pumps, piping, etc.)	$43,000	
Miscellaneous (mobilization, IDW disposal, etc.)	$12,000	
Subtotal	$188,900	
Indirect capital		
Engineering (15%)	$28,400	
Contingency (25%)	$47,300	
Subtotal	$75,700	
Total capital		$265,000
Annual O&M:		
Maintenance and inspection	$13,000	
Periodic major repair	$7,000	
Annual monitoring and reporting	$27,000	
Pump replacement	$3,000	
Electricity	$5,000	
Subtotal	$55,000	
Present worth O&M (5%, 30 yr.)		$846,000
Total present value (capital and present worth O&M)		$1,111,000

Table 4. Cost Estimate for
Upgrade of Existing Groundwater Treatment System
Alternative S-3-1
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Ancillary equipment (replacement pumps, piping, etc.)	$8,000	
New influent/effluent tanks	$100,000	
Miscellaneous (preheater upgrade, etc.)	$10,000	
Subtotal	$118,000	
Indirect capital		
Engineering (15%)	$17,700	
Contingency (25%)	$29,500	
Subtotal	$47,200	
Total capital		$166,000
Annual O&M:		
Chemical additatives ($1.5/1000 gal)	$50,000	
Subtotal	$50,000	
Present worth O&M (5%, 30 yr.)		$769,000
Total present value (capital and present worth O&M)		$935,000

Table 5. Cost Estimate for
New Pre-Treatment System for Vinyl Chloride and Upgrade of Existing Groundwater Treatment System
Alternative S-3-2
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Upgrade of existing GWTP	$118,000	
New equlibrium tank	$14,400	
New low profile plate air stripper	$29,500	
Cataylitic oxidizer	$78,000	
Miscellaneous (interconnect piping, etc.)	$10,000	
Subtotal	$249,900	
Indirect capital		
Engineering (15%)	$37,500	
Contingency (25%)	$62,500	
Subtotal	$100,000	
Total capital		$349,900
Annual O&M:		
Catalytic oxidizer fuel	$21,500	
Chemical additives for existing GWTP	$50,000	
Electricity	$3,700	
Peridioc major repair	$7,800	
Subtotal	$83,000	
Present worth O&M (5%, 30 yr.)		$1,276,000
Total present value (capital and present worth O&M)		$1,626,000

Table 6. Cost Estimate for
Industrial Wastewater Treatment Plant System
Alternative S-3-4
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Miscellaneous	$10,000	
Subtotal	$10,000	
Indirect capital		
Engineering (15%)	$1,500	
Contingency (25%)	$2,500	
Subtotal	$4,000	
Total capital		$14,000
Annual O&M:		
Chemical treatment ($1.73/1000gal)	$59,000	
Subtotal	$59,000	
Present worth O&M (5%, 30 yr.)		$907,000
Total present value (capital and present worth O&M)		$921,000

Table 7. Cost Estimate for
Discharge treated water to POTW
Alternative D-1
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Ancillary equipment (pumps, piping, etc.)	$00	
Subtotal	$00	
Indirect capital		
Engineering (15%)	$00	
Contingency (25%)	$00	
Subtotal	$00	
Total capital		$00
Annual O&M:		
Discharge costs ($1.76/1000gal)	$00	
Subtotal	$00	
Present worth O&M (5%, 30 yr.)		$000
Total present value (capital and present worth O&M)		$0

Table 8. Cost Estimate for
Discharge treated water to POTW
Alternative D-2
Tinker AFB, Oklahoma

Capitol costs:		
Direct Capitol		
Ancillary equipment (pumps, piping, etc.)	$3,000	
Subtotal	$3,000	
Indirect capital		
Engineering (15%)	$500	
Contingency (25%)	$800	
Subtotal	$1,300	
Total capital		$5,000
Annual O&M:		
Discharge costs ($1.76/1000gal)	$60,000	
Subtotal	$60,000	
Present worth O&M (5%, 30 yr.)		$923,000
Total present value (capital and present worth O&M)		$928,000

Tinker Air Force Base
Industrial Wastewater Treatment Plant/ Soldier Creek Off-Base Groundwater Operable Units

Additional Modeling for Soldier Creek Groundwater RI/FS

Draft Letter Report

Submitted to

Department of the Air Force
Oklahoma City Air Logistics Center
Tinker Air Force Base, Oklahoma

Contract Number: F34650-93-D-0106
Delivery Order: 5001

June 1996

ENGINEERING-SCIENCE, INC.

8000 Centre Park Drive, Suite 200 • Austin, Texas 78754 • (512) 719-6000 • Fax: (512) 719-6099

July 31, 1996

Via Federal Express

Mr. Gordon Mohon
Contracting Officer
OC-ALC/PKOSS
7858 5th Street, Suite 1
Tinker AFB, OK 73145-9106

Subject: Additional Modeling for
IWTP/Soldier Creek Off-Base Groundwater Operable Units RI/FS
Draft Letter Report
USAF contract F34650-93-D-0106, D.O. 5001
Parsons ES job number 721447.1104

Dear Mr. Mohon:

Enclosed please find one copy of the draft letter report on the results of additional modeling for the IWTP/Soldier Creek Off-Base Groundwater Operable Units RI/FS. We have also sent five copies directly to James Dawson, as he directed.

If you have any questions, please do not hesitate to call me.

Sincerely,

Julie Burdey for

John K. Yu, Ph.D, C.G.W.P., P.G.
Project Manager

xc: James Dawson, OC-ALC/EMR (5 copies)
Jack Sullivan, Parsons ES - OKC (1 copy)
Ken Rice, Parsons ES (1 copy)
Julie Burdey, Parsons ES (1 copy)
Jay Snow, Parsons ES (letter only)
Charles Spiers, Parsons ES-Atlanta (letter only)

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ATTACHMENT 1

DRAFT LETTER REPORT

ADDITIONAL MODELING FOR SOLDIER CREEK GROUNDWATER RI/FS

INTRODUCTION

The remedial investigation of the Soldier Creek Groundwater Operable Unit identified a number of contaminants in the groundwater flow system. The baseline risk assessment identified vinyl chloride in six monitoring wells that had concentrations of vinyl chloride resulting in and contributing to estimates of cancer risk above the acceptable health protective risk range (1E-04 to 1E-06). In addition, chromium, nickel, TCE, and PCE were detected beneath the IWTP facility. Up to a total of nine extraction wells have been proposed as part of the feasibility study to remove and contain the contaminated groundwater. The purpose of this letter report is to evaluate the proposed well locations and pumping rates according to their ability to contain and remove the contaminated groundwater.

Groundwater flow modeling and particle tracking techniques were used to evaluate recovery well locations and pump rates as suggested in Figure 5.1 in the draft IWTP/Soldier Creek Off-Base Groundwater Operable Units Feasibility Study. Nine extraction wells installed at four well sites are included in the proposed design. Site PR-1 consists of a well screened in layer 3 and a well screened in layer 7. Well sites PR-2 and PR-3 consist of wells screened in layers 3, 5, and 7. Well site PR-4 has a single well screened in layer 5.

The northeast quadrant groundwater flow model was used to simulate the effect of extracting groundwater from the wells according to each of the scenarios. The limitations and assumptions presented in the Groundwater Flow and Solute Transport Modeling Draft report (Battelle, 1995) are applicable here. Particle tracking (reverse) from the proposed extraction well locations over a 25 year time period has been conducted from each well using a 3-D version of the 2-D Random Walk code (Prickett et. al, 1981), RWLK3D, developed at Battelle. Time-of-travel capture zones for 5 and 25 years have been overlain upon the simulated water level maps and contaminant distribution maps for layers 3, 5, and 7 (Displaying 5-year time-of-travel capture zones for 5, 10, 15, 20, and 25 years became illegible, and as a result, only the 5- and 25-year time-of-travel capture zones are presented). The time-of-travel capture zones are overlain upon the contaminant distribution maps to permit a rapid evaluation of the effectiveness of different extraction well pumping scenarios. Contaminant distribution maps selected for layer 3 include chromium, nickel, PCE, and TCE. For layer 5, chromium, PCE, TCE, and vinyl chloride are included. For layer 7, chromium, nickel, PCE, and vinyl chloride have been included. Capture zones were determined using advective flow only. The effects of retardation for the different contaminants can be related to the advective capture zones using the contaminant specific retardation factors.

The proposed extraction wells occur in the recharge area for the LSZ sediments. Vertical groundwater flow gradients in this area are significant. The reverse particle tracking techniques result in 3-D capture zones in which pathlines often cross into the overlying layer(s). The capture zones presented on the figures, therefore, represent the 2-D extent of the 3-D capture zone for each scenario and may appear to deviate from the expected flow directions indicated by the water level contours.

The capture zones are indicated by bold black lines on each of the figures. The 5-year capture zone is typically the smaller of the two. In many instances, the 3-D capture zones of adjacent wells overlap on the 2-D figures. This is a limitation of displaying a 3-D object on a 2-D map. In addition, the accuracy of the capture zones is dependent upon how representative the steady-state flow fields are of future flow conditions at the site. Should flow directions and gradients change in response to new stresses on the system such as increased recharge from climatic changes, then the shape and extent of the capture zones will also be somewhat affected.

The modeling scenarios completed in support of the SCGW feasibility study include the following:

1. The well-field design as suggested in Figure 5.1 of the FS
2. Elimination of Well PR-4
3. Elimination of PR-4 as well as all layer 3 wells
4. Any other suggested alternate scenarios.

The scenarios are being completed in two phases or tasks. In the first task, scenarios 1 through 3 were completed according to the design (pumping rates and well locations) suggested in the FS. Task 2 (Scenario 4) consists of identifying alternate scenarios relative to scenarios 1 through 3 that may be more effective at removing contamination from within the conceptual model area. Task 2 has been broken into 2 subtasks (Task 2A and Task 2B) to examine flow rates and proposed extraction well locations. In Task 2A, the maximum sustainable flow rates for Scenarios 1 through 3 as described above were determined. In Task 2B the movement of the PR-3 location to the west of its current location was evaluated.

TASK 1:

Three flow model simulations for Task 1 have been completed according to the locations and pump rates presented in the Draft Feasibility report. The simulations correspond to Scenarios 1 through 3 as described above and are referenced as SC-1, SC-2, and SC-3, respectively. The results from each of the scenarios completed under Task 1 are summarized in Table 1.

Table 1. Summary of results from scenarios 1 through 3 under Task 1.

WELL	WELL LOCATION			RATE	RUN		
	LAYER	ROW	COLUMN	(FT^3/DAY)	SC1	SC2	SC3
PR-1	3	53	44	385	DRY*	DRY	NS*
PR-2		61	46	385	DRY	DRY	NS
PR-3		64	51	385	OK*	OK	NS
PR-2	5	61	46	1925	DRY	DRY	DRY
PR-3		64	51	1925	OK	OK	OK
PR-4		77	50	1925	DRY	NS	NS
PR-1	7	53	44	1925	OK	OK	OK
PR-2		61	46	1925	OK	OK	OK
PR-3		64	51	1925	OK	OK	OK

DRY: indicates pump rate dewatered cell during MODFLOW simulation.
NS: indicates that the well at this location was not simulated in the scenario.
OK: indicates that the pump rate was sustainable.

TASK 1, Scenario 1:

Scenario 1 consisted of 3 wells in each of the three layers for a total of 9 proposed extraction wells. Layer 3 wells at locations PR-1 and PR-2 went dry during the simulation indicating that the proposed flow rates are too high to be sustained over long-term pumping. Similarly, two proposed wells (locations PR-2 and PR-4) in layer 5 also went dry during the simulation. None of the proposed wells in layer 7 went dry during the simulation.

Figures 1 through 4 show the capture zones superimposed upon the distributions of Cr, Ni, PCE, and TCE, respectively for layer 3. Only the capture zones for PR-3 are presented as the locations for PR-1 and PR-2 could not support the proposed pumping rate and dewatered during the simulation. As can be seen on all 4 figures, the capture zone for PR-3 in layer 3 is small in areal extent, and is limited by a groundwater flow divide located directly east of the proposed extraction well location. The 5-year and 25-year time-of-travel capture zones are nearly the same size in areal extent. They also indicate that the location of the proposed well on the edge of the plumes will result in the removal of only a small mass of contaminants and a much larger proportion of non-contaminated groundwater.

Figures 4 through 8 show the capture zones superimposed upon the distributions of Cr, PCE, TCE, and vinyl chloride in layer 5. Only the capture zones for the well at PR-3 are shown. Extraction rates at PR-2 and PR-4 resulted in dewatering of the aquifer during the simulation. The location of the well near the edge of the contaminant plumes results in the simulated capture of a larger area of non-contaminated groundwater relative to the area of contamination.

Figures 9 through 12 show the capture zones overlain upon the selected contaminants in layer 7. The saturated thickness in this layer is much greater relative to layers 3 and 5, and as a result can sustain the higher proposed pumping rates. None of the proposed wells went dry during this simulation. The capture zones are large in areal extent and appear to contain or capture much of the contaminated groundwater in layer 7. After 25 years of simulated operation, the model predicts that the proposed wells will also have captured a large volume of non-contaminated groundwater.

TASK 1, Scenario 2:

Scenario 2 consisted of the same design as Scenario 1 with the exception that the proposed well at location PR-4 in layer 5 was removed from the simulation (8 proposed extraction wells). Again, layer 3 wells at locations PR-1 and PR-2, and the layer 5 well at location PR-2 went dry during the simulation. Capture zones for the wells that did not go dry in layers 3, 5, and 7 were overlain upon the respective contaminant distribution maps for each layer. The resultant capture zones in layers 3 and 7 were nearly identical to those presented in Task 1, Scenario 1, and are not presented again. Figures 13 through 16 illustrate the capture zones for layer 5 overlain upon the selected contaminants. Results for all layers are nearly identical to those presented under Task 1, scenario 1 and are not described or included in this letter report.

TASK 1, Scenario 3:

In scenario 3, the proposed extraction wells in layer 3 were not simulated nor was the proposed well at location PR-4 in layer 5. The proposed well at PR-2 in layer 5 went dry during the simulation. As a result, the capture zones generated for layers 5 and 7 are very similar to the capture zones shown under Task 1, Scenario 1 for layer 7 (Figures 8 through 12), and Task 1, Scenario 2 for layer 5 (Figures 13 through 16). Because there is virtually no difference between the capture zones presented for these layers, the figures are not repeated here.

The results from the 3-D modeling of scenarios 1 through 3 indicate the proposed extraction rates from several of the locations (PR-1 and PR-2 in layer 3, PR-2 and PR-4 in layer 5) are too high to be sustained over long term pumping and will result in dewatering of the aquifer near the proposed wells. In addition, the locations of several of the wells results in the capture of non-contaminated groundwater and could be moved downgradient to contain/extract more contaminant mass. The reasons for dry cells/differences between MODFLOW (3-D modeling) and QUICKFLOW/Drawdown superposition (2-D) are believed to be the result of several factors including the following:

- The 3-D simulations incorporate interference from Building 3001 extraction system.
- The 3-D model uses actual layer thickness at each of the locations--layer 3 wells in areas of thinner saturation (PR-1 roughly 10 feet).
- The 3-D simulations incorporate vertical flow/interference between adjacent layers

TASK 2:

Task 2 consists of two major subtasks denoted as Task 2A and Task 2B. Effort on Task 2A focused on determining the maximum sustainable flow for the proposed extraction well configurations in scenarios 1 through 3. Proposed wells that dewatered in the scenarios completed in Task 1 were simulated to determine what flow rates could be sustained over a period of 25 years. In Task 2B the movement of the proposed extraction well locations are evaluated based upon their resultant capture zones.

TASK 2A: Determination of Maximum Sustainable Flow Rates

Over 50 groundwater flow simulations have been performed in an attempt to determine the maximum sustainable (long-term steady state) flow rates for the extraction wells. Water level maps for each of these simulations have been prepared. Particle tracking/capture zone delineation were completed to illustrate capture zones for the proposed extraction wells. The water level contours, time-of-travel capture zones and contaminant plumes have been superimposed on the maps for each layer for the runs illustrating the maximum sustainable flow rates for the extraction well configurations in each of the scenarios 1 through 3. The resultant flow rates determined under Task 2A are summarized in Table 2.

For Scenario 1 in which all 9 of the proposed extraction wells are simulated, Figures 17 through 20 show the capture zone for PR-3 in layer 3 overlain upon the selected contaminant plumes. A pumping rate of 500 cubic feet per day or 2.6 gpm was simulated at this location. Locations PR-1 and PR-2 could not sustain significant flow rates, and capture zones are not presented for these locations. Figures 21 through 24 illustrate the capture zones in layer 5 overlain upon the selected contaminant plumes. Figures 25 through 28 illustrate the capture zones in layer 7 for this scenario.

In Task 2A, Scenario 2, eight of the proposed extraction wells were simulated. Only the well at PR-4 in layer 5 was removed. The resultant capture zones for layers 3 and 7 are very similar to those generated under Task 2A, Scenario 1 and are not repeated here. Figures 29 through 32 illustrate the capture zones in layer 5 overlain upon the selected contaminant plumes for this scenario.

In Task 2A, Scenario 3, five of the proposed extraction wells (layer 5 wells at PR-2 and PR-3, and all three layer 7 wells) were simulated. Examination of the results indicated that the capture zones generated here for layers 5 and 7 were very similar to those generated in Task 2A, Scenario 2 and Scenario 3, respectively.

Table 2. **Summary of results from scenarios 1 through 3 under Task 2A to develop maximum sustainable flow rates for the proposed extraction well locations.**

WELL	WELL LOCATION			RATE	RUN		
	LAYER	ROW	COLUMN	(FT^3/DAY)	SC1	SC2	SC3
PR-1	3	53	44	—	DRY*	DRY	DRY
PR-2		61	46	3	OK	OK	NS
PR-3		64	51	500	OK	OK	NS
PR-2	5	61	46	962.5	OK	OK	OK
PR-3		64	51	1925	OK	OK	OK
PR-4		77	50	240.5	OK	NS	NS
PR-1	7	53	44	1925	OK	OK	OK
PR-2		61	46	1925	OK	OK	OK
PR-3		64	51	1925	OK	OK	OK

DRY: indicates pump rate dewatered cell during MODFLOW simulation. This location dewatered even though extraction well was simulated here.
NS: indicates that the well at this location was not simulated in the scenario.
OK: indicates that the pump rate was sustainable.

As indicated in Table 2, the proposed wells in layer 3 at locations PR-1 and PR-2 can not sustain significant flow rates. The saturated thickness at these locations is thin and has been reduced somewhat by the operation of the Building 3001 extraction system. These areas also occur within the containment zone for the Building 3001 extraction system. Therefore, it is recommended that these locations be removed from consideration for installation of new extraction wells.

Examination of the capture zones for the remaining locations indicates that the proposed well in layer 5 at PR-4 will have little affect on the contaminant distributions. Again, this location falls within the containment zone for the Building 3001 extraction system. As a result, it is also recommended that this location be removed from consideration for installation of new extraction wells.

The capture zones for the remaining wells (PR-1 in layer 7, PR-2 in layers 5 and 7, PR-3 in layers 3, 5, and 7) have been evaluated to determine their effectiveness at containment and removal of contaminated groundwater. Based on the modeling results, the proposed wells at the PR-2 location are most effective at removing contaminated groundwater relative to PR-1 and PR-3. Both PR-1 and PR-3 locations result in the capture of a significant proportion of non-contaminated groundwater and may draw contamination out towards these locations.

TASK 2B: Movement of proposed well locations.

Based on the results from Task 1 and Task 2A, the proposed locations for PR-1, layer 7, and PR-3, (layers 3, 5, and 7) were moved to new locations in an attempt to enhance their effectiveness at containing and extracting the contaminant plumes. Water level and contaminant distribution maps and the modeling results were reviewed to select the new locations. The extraction well at PR-1 in layer 7 was moved to the south near the TOB-6 where the highest concentration of vinyl chloride was measured. The PR-3 extraction wells in layers 3, 5, and 7 were moved approximately 200 feet west of their proposed location. Movement of PR-3 wells 200 feet to the west of its original location resulted in significant interference with the PR-2 location. One final run was completed where the PR-2 wells were moved north towards the 1-11 well cluster location. The locations and pumping rates for this run are presented in Table 3. In this simulation, 5 wells (two in layer 5, and 3 in layer 7) were simulated. All but the layer 5 well at PR-2 were able to sustain pumping rates of 10 gpm. The maximum predicted rate for the layer 5 well at PR-2 is between 1 and 2 gpm. Figures 33 through 36 illustrate the layer 5 capture zones. Figures 37 through 40 illustrate the capture zones in layer 7.

Table 3. Summary of well locations and pump rates under Task 2B.

WELL	WELL LOCATION			SPCS COORDINATES		RATE
	LAYER	ROW	COLUMN	EASTING	NORTHING	(FT^3/DAY)
PR-2	5	58	46	2,186,500	156,100	250
PR-3		64	51	2,187,000	155,500	1925
PR-1	7	53	44	2,186,300	156,600	1925
PR-2		58	46	2,186,500	156,100	1925
PR-3		64	51	2,187,000	155,500	1925

TASK 2B: Forward Particle Tracking from Vinyl Chloride Hits

Forward particle tracking was performed from the six monitoring wells in which vinyl chloride was detected to evaluate the effects if no new extraction wells are installed. The six monitoring wells are 1-50BR in layer 3; 1-50AR, 1-51AR, and 22DR in layer 5; and 1-51C and TOB-6C in layer 7. One thousand particles were placed around a cylindrical source and tracked forward through the groundwater flow field for a period of 100 years while saving the intermediate results every 4 years. Figures 41 through 43 illustrate the flow paths overlain on the simulated water level surfaces for each of the particles in layers 3, 5, and 7, respectively. Steady state flow fields which include the operation of the Building 3001 groundwater extraction system were used as input to the particle tracking simulation. Each of these figures (Figures 41 through 43) shows that the flow directions are primarily to the west or southwest towards the Building 3001 extraction system. Most of the particles reach the location of a Building 3001 extraction well within the simulated 100 year time frame. No particles were observed to migrate off base to the north or east in this simulation. The results from this scenario will be representative as long as flow directions and gradients do not change significantly from the simulated steady-state flow field.

SUMMARY

Groundwater flow modeling in support of the Soldier Creek Feasibility study was completed to evaluate the well field design as suggested in Figure 5.1 of the FS report. Variations on the number of wells and pump rates were examined to determine the maximum sustainable flow rates at the proposed locations. The modeling results indicated that there was not sufficient saturated thickness in layer 3 at the PR-1 and PR-2 locations to support long term extraction as sustainable rates. In addition, locations PR-1, PR-3, and PR-4 are near the upgradient edge of the contaminant plumes, and prolonged pumping from these locations will result in the capture of a significant proportion of non-contaminated groundwater.

Several additional simulations were completed to determine if new locations and pump rates could be selected that would enhance plume recovery. The last scenario included 5 wells, 2 in layer 5 and 3 in layer 7. The wells were located at or just downgradient from the hot spots to permit more effective removal of the contaminant plumes. At these new locations, a significant proportion of non-contaminated water is still captured after prolonged pumping. In all cases, the contamination occurring immediately beneath the IWTP area lies within the containment zone of the Building 3001 extraction system and will eventually move towards those extraction wells. Forward particle tracking from the six locations where vinyl chloride was detected (only the Building 3001 extraction system was simulated and none of the proposed wells were simulated) indicated flow was towards the extraction system and off base migration of contamination from these locations does not appear to occur.

RECOMMENDATIONS

Based on the results of the forward particle tracking completed under Task 2B, it appears that additional extraction wells are not needed to prevent the off base migration of contaminated Soldier Creek/IWTP groundwater. Flow directions are to the west southwest towards the Building 3001 extraction system under the conditions simulated. Installation of additional extraction wells would expedite the removal of contaminated groundwater from the IWTP/Soldier Creek Groundwater Operable Units, but areas of low contaminant levels would likely remain, even after 25 years of pumping based on the results of simulations completed to date. In the event that additional extraction will be installed, the following recommendations are made with regards to the proposed extraction well locations for the IWTP/Soldier Creek Groundwater Operable Units:

- Layer 3, locations PR-1 and PR-2 have very thin saturated thickness and will not support long term pumping rates and should be removed from consideration as new extraction well locations

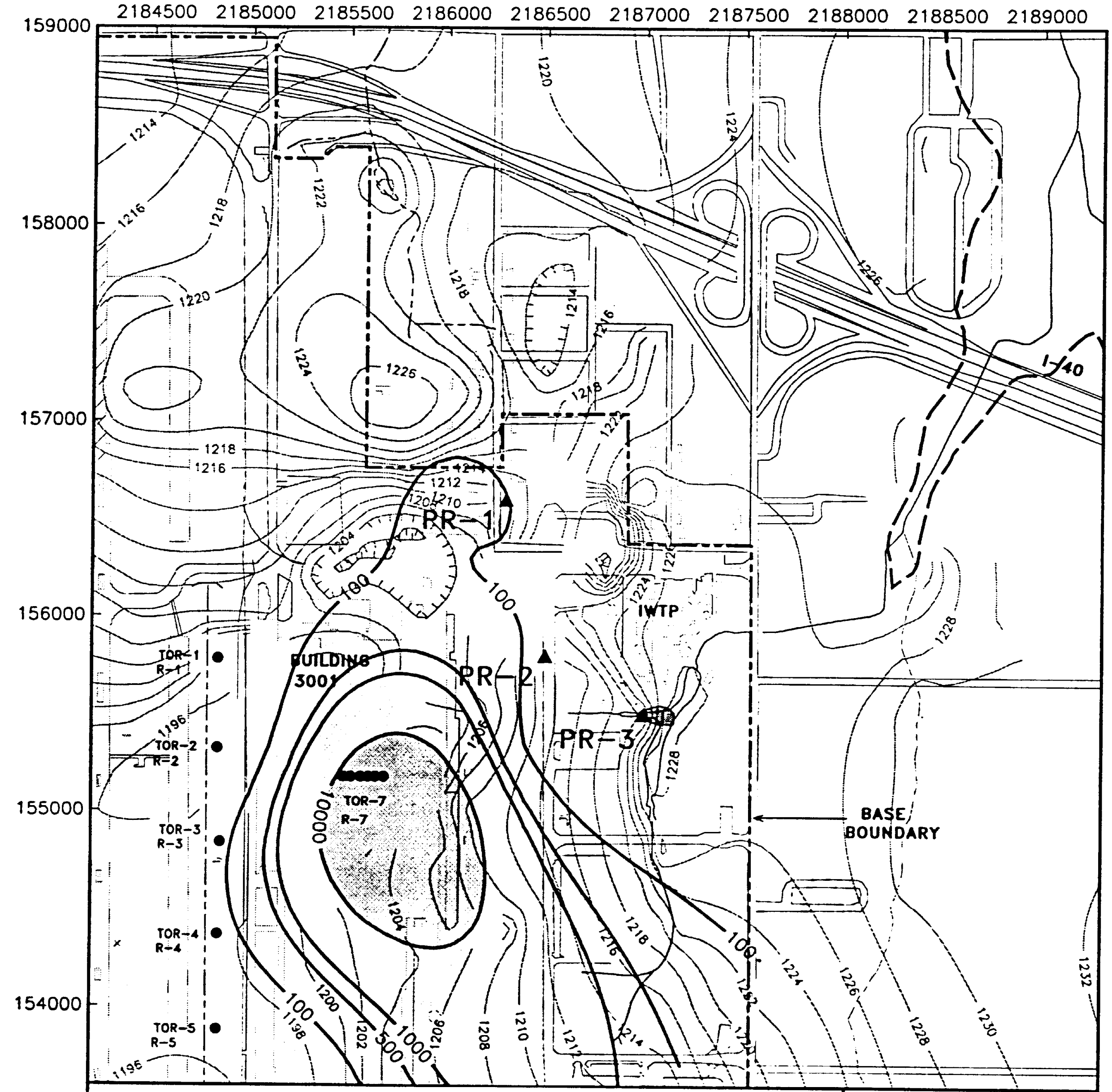
- Layer 5, location PR-4 will remove primarily non-contaminated groundwater and should be removed from consideration as new extraction well.

- Revised locations PR-1 for layer 7, and PR-2 and PR-3 for layers 5 and 7 as specified in Table 3 are preferable to the design presented in Figure 5.1 of the FS report. Operation of these wells should be closely monitored because after 5 years of pumping at the rates presented in Table 3, a significant proportion of non-contaminated water would be captured.

RECOMMENDATIONS continued

- Use existing wells (the wells with vinyl chloride hits) as extraction wells rather than installing new wells at the locations specified in Table 3.

- Perform an additional modeling scenario to determine the location, pump rate, and number of extraction wells needed to produce 5-year time-of-travel capture zones that would encompass the current extent of IWTP/Soldier Creek groundwater contamination in layers 5 and 7.



▲ PR-2 — Proposed Well, Well ID

● TOR-7 R-7 — B3001 Extraction Well, Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 3
Isopleth Line

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

TN MN
0° 22' — 7.5° (1986)

1000 500 0 500 1000
FEET

CR Concentration
100–10,000 PPB
>10,000 PPB

Capture Zones
5 Years
25 Years

Figure 1

Scenario 1
Layer 3 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc1l3hd1.ps
Date: 7/29/96

BATTELLE

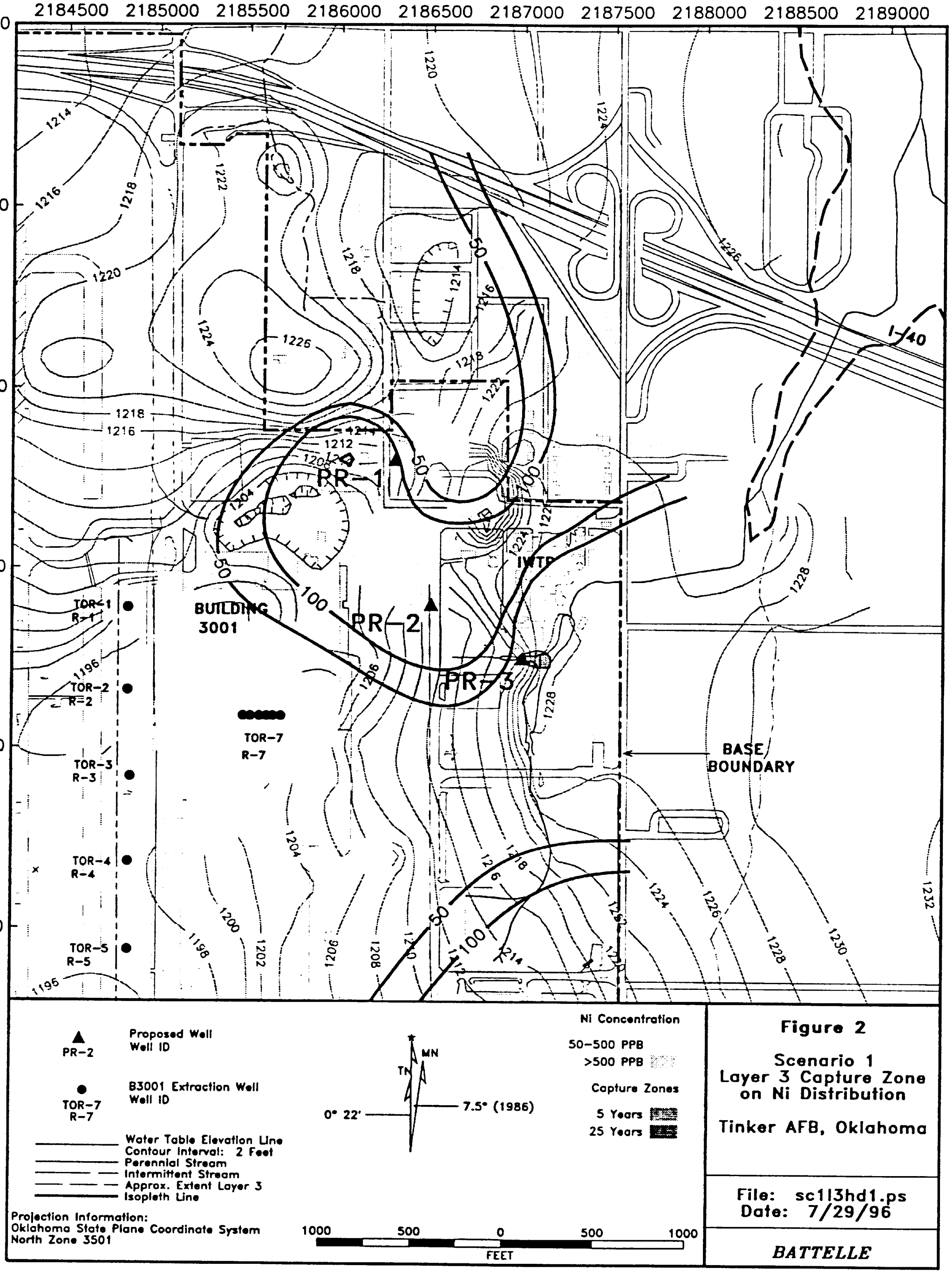


Figure 2

Scenario 1
Layer 3 Capture Zone
on Ni Distribution

Tinker AFB, Oklahoma

File: sc1l3hd1.ps
Date: 7/29/96

BATTELLE

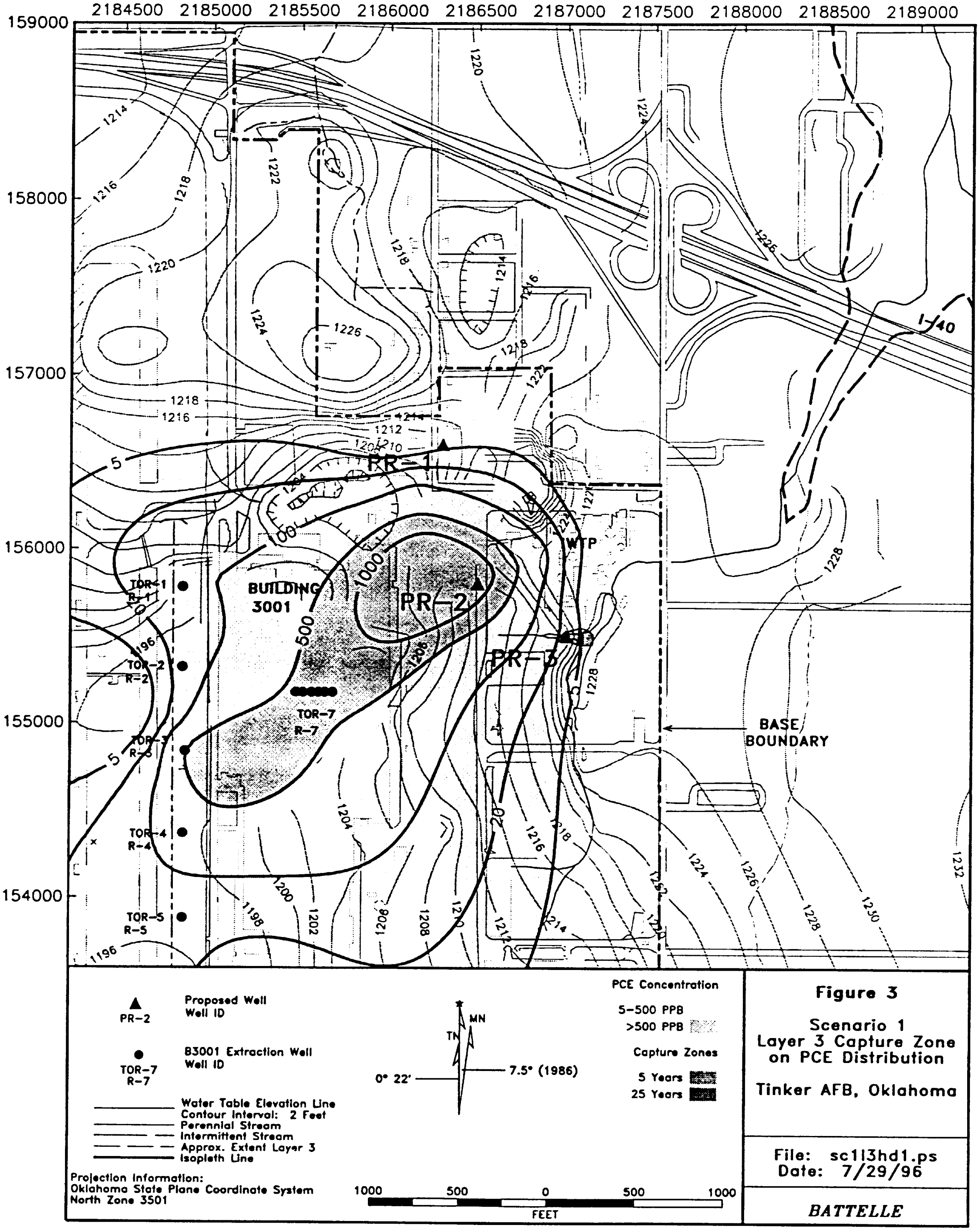


Figure 3
Scenario 1
Layer 3 Capture Zone on PCE Distribution
Tinker AFB, Oklahoma

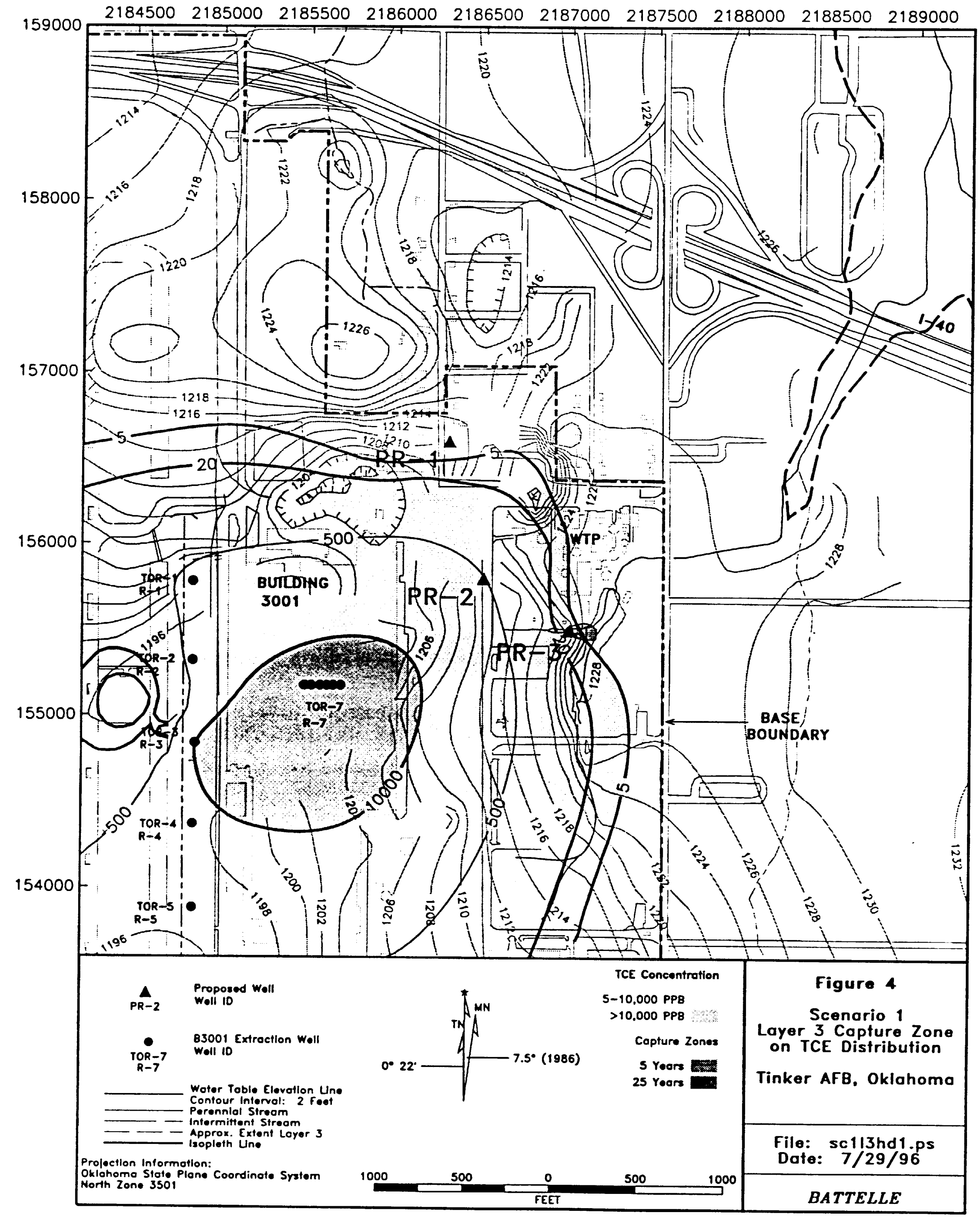


Figure 4

Scenario 1
Layer 3 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc1l3hd1.ps
Date: 7/29/96

BATTELLE

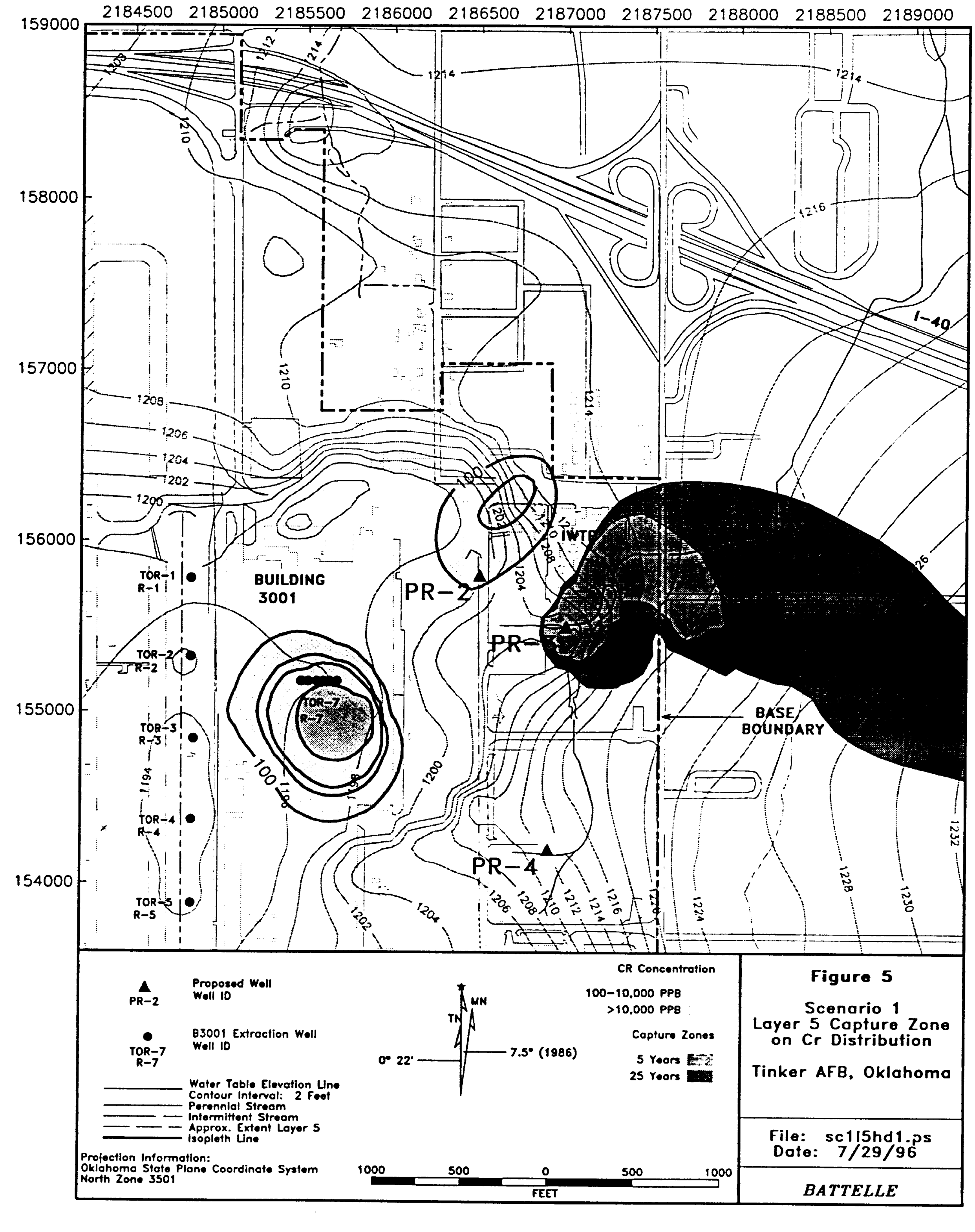


Figure 5

Scenario 1
Layer 5 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc115hd1.ps
Date: 7/29/96

BATTELLE

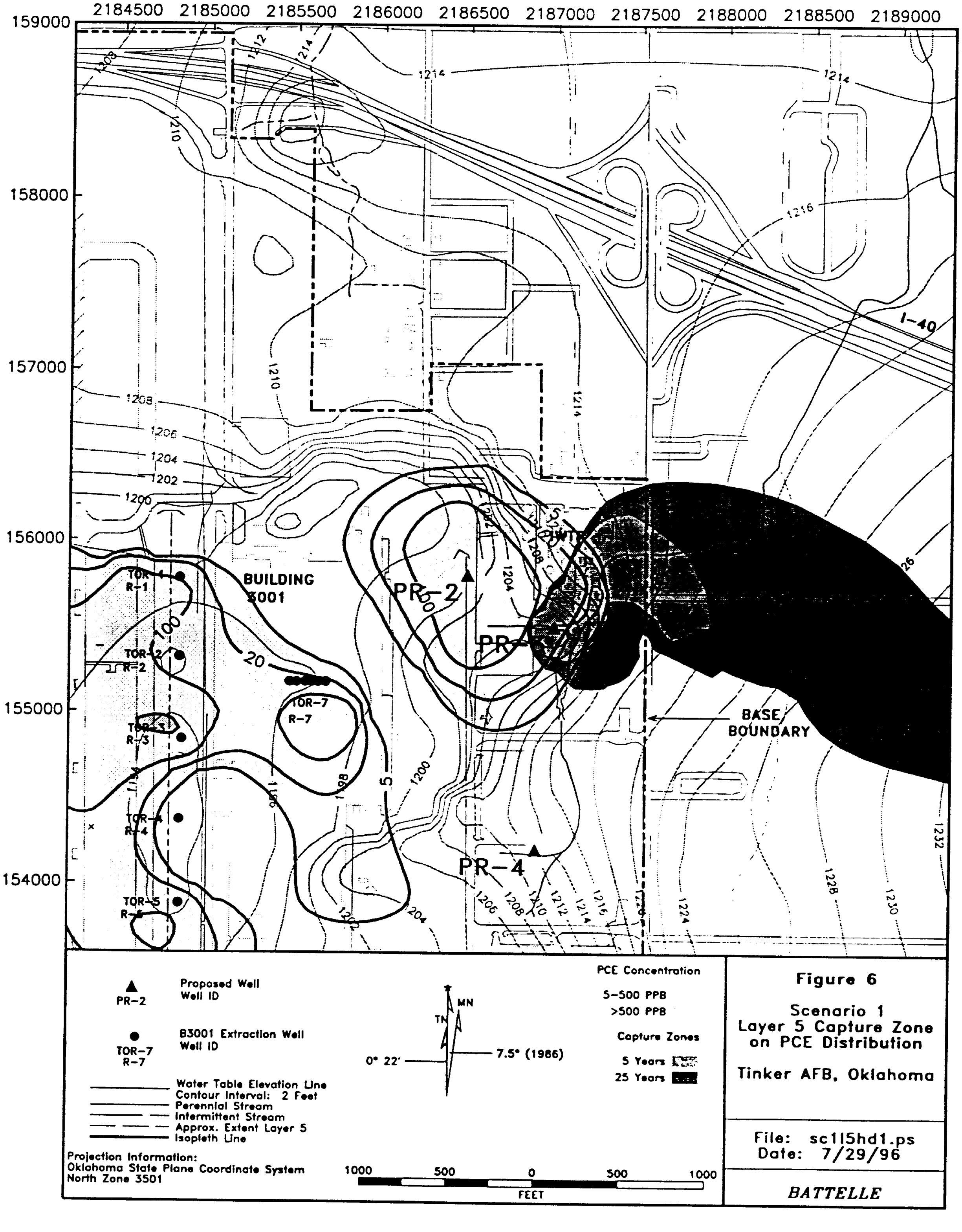


Figure 6

Scenario 1
Layer 5 Capture Zone
on PCE Distribution

Tinker AFB, Oklahoma

File: sc115hd1.ps
Date: 7/29/96

BATTELLE

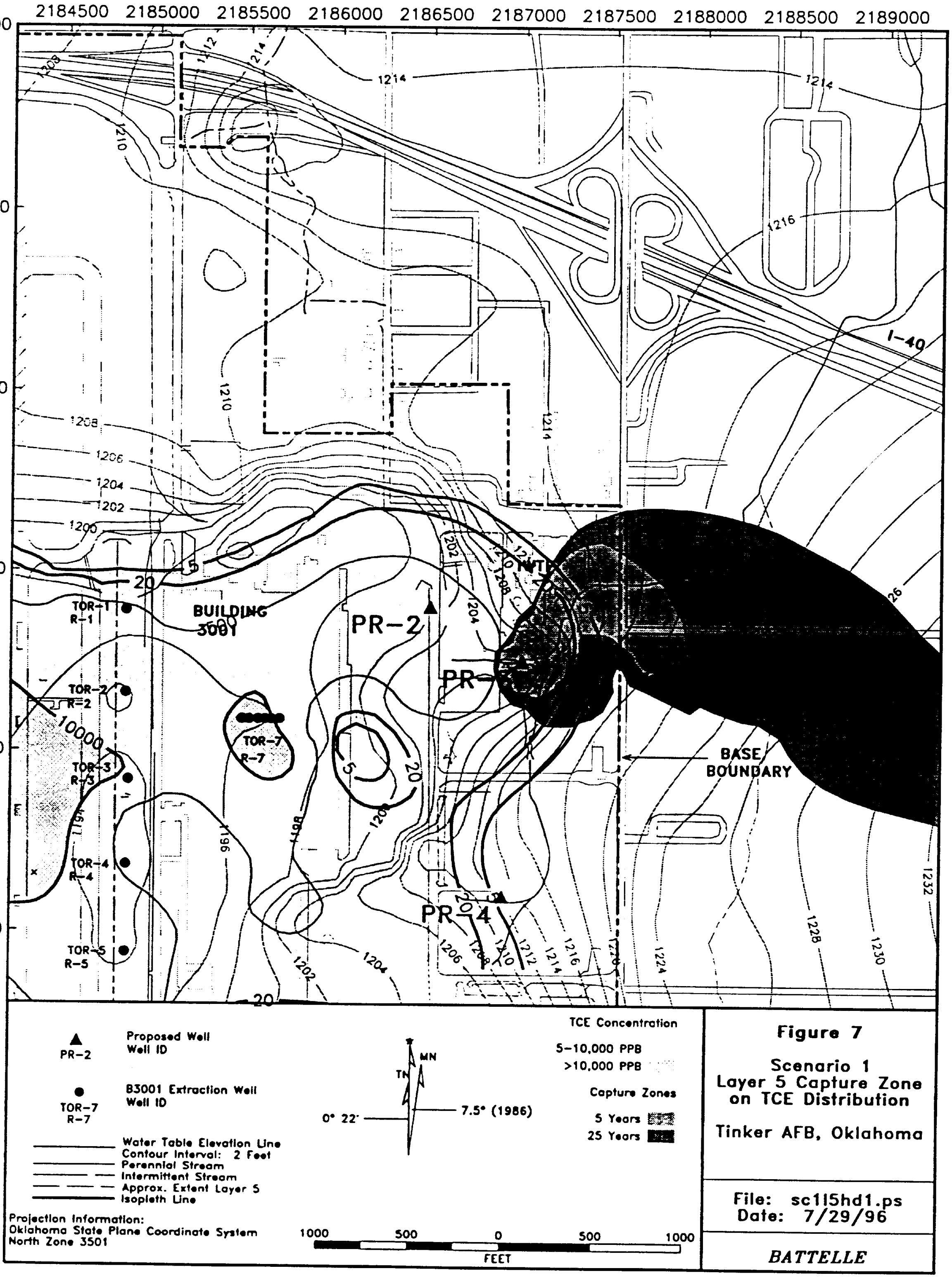


Figure 7

Scenario 1
Layer 5 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc115hd1.ps
Date: 7/29/96

BATTELLE

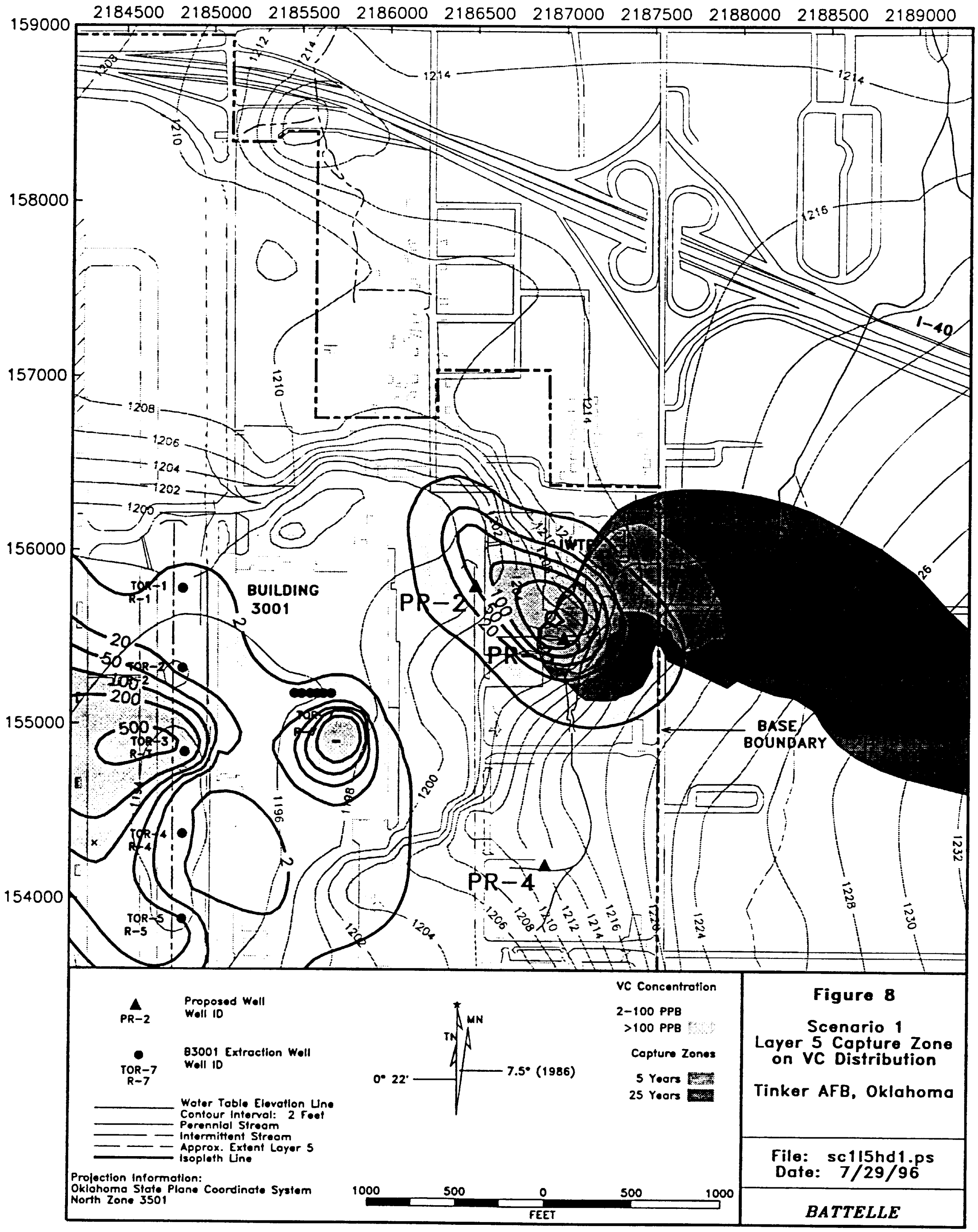


Figure 8

Scenario 1
Layer 5 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc115hd1.ps
Date: 7/29/96

BATTELLE

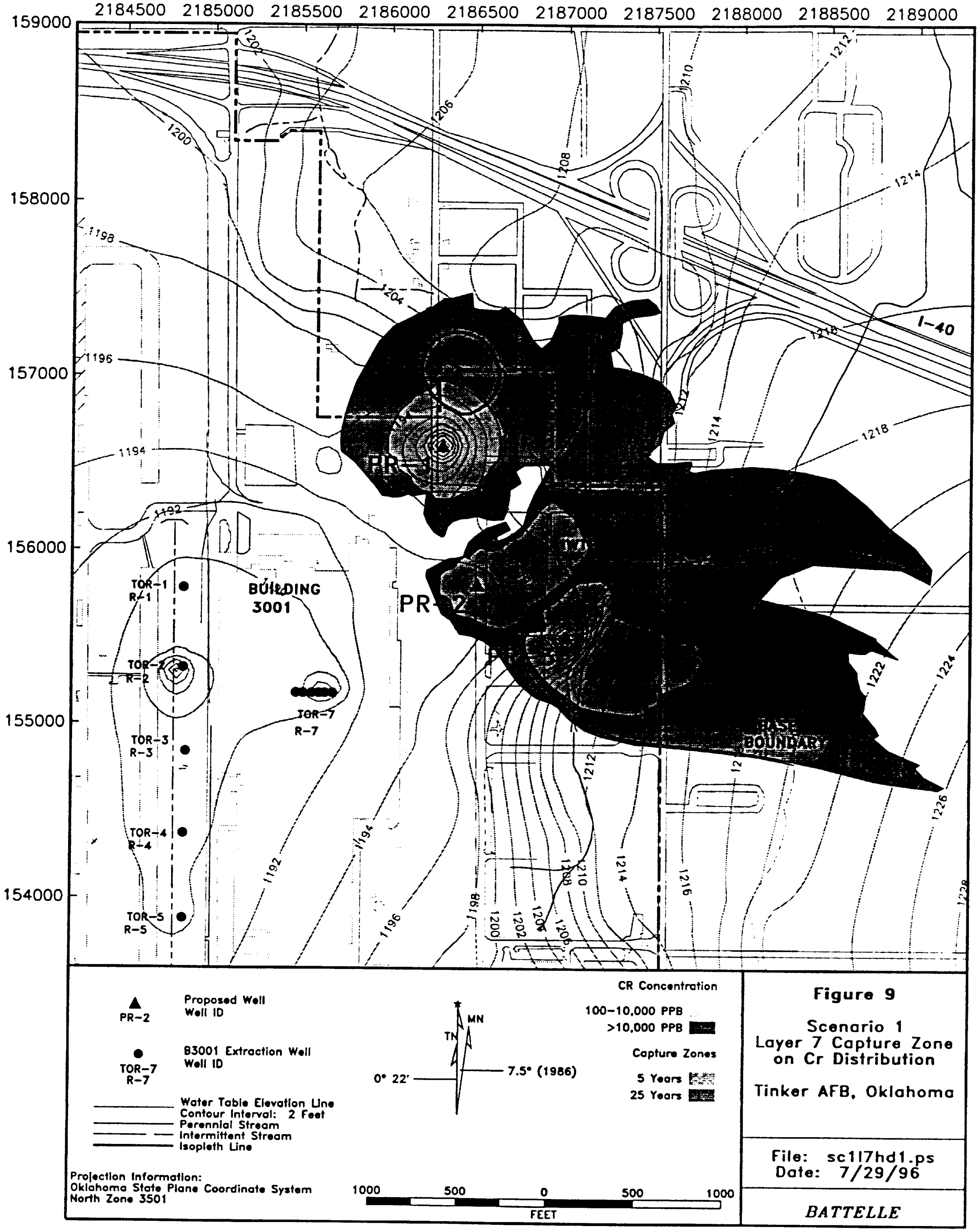
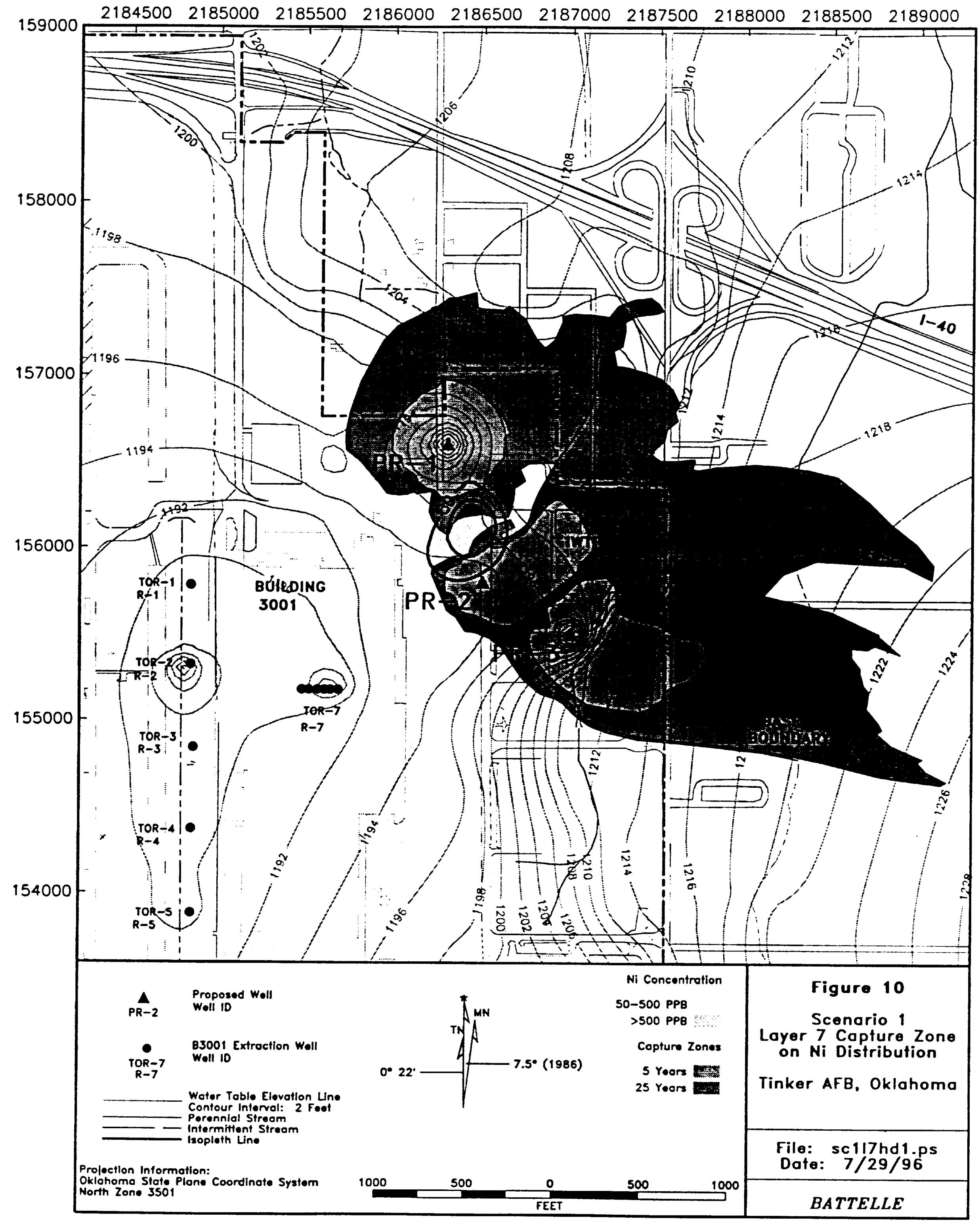


Figure 9

Scenario 1
Layer 7 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma



2184500 2185000 2185500 2186000 2186500 2187000 2187500 2188000 2188500 2189000
159000
158000
157000
156000
155000
154000
I-40
BUILDING 3001
PR-1
PR-2
TOR-1 R-1
TOR-2 R-2
TOR-3 R-3
TOR-4 R-4
TOR-5 R-5
TOR-7 R-7
Proposed Well
Well ID
B3001 Extraction Well
Well ID
Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Isopleth Line
Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501
TN
MN
0° 22'
7.5° (1986)
1000 500 0 500 1000
FEET
Ni Concentration
50-500 PPB
>500 PPB
Capture Zones
5 Years
25 Years
Figure 10
Scenario 1
Layer 7 Capture Zone
on Ni Distribution
Tinker AFB, Oklahoma
File: sc1l7hd1.ps
Date: 7/29/96
BATTELLE

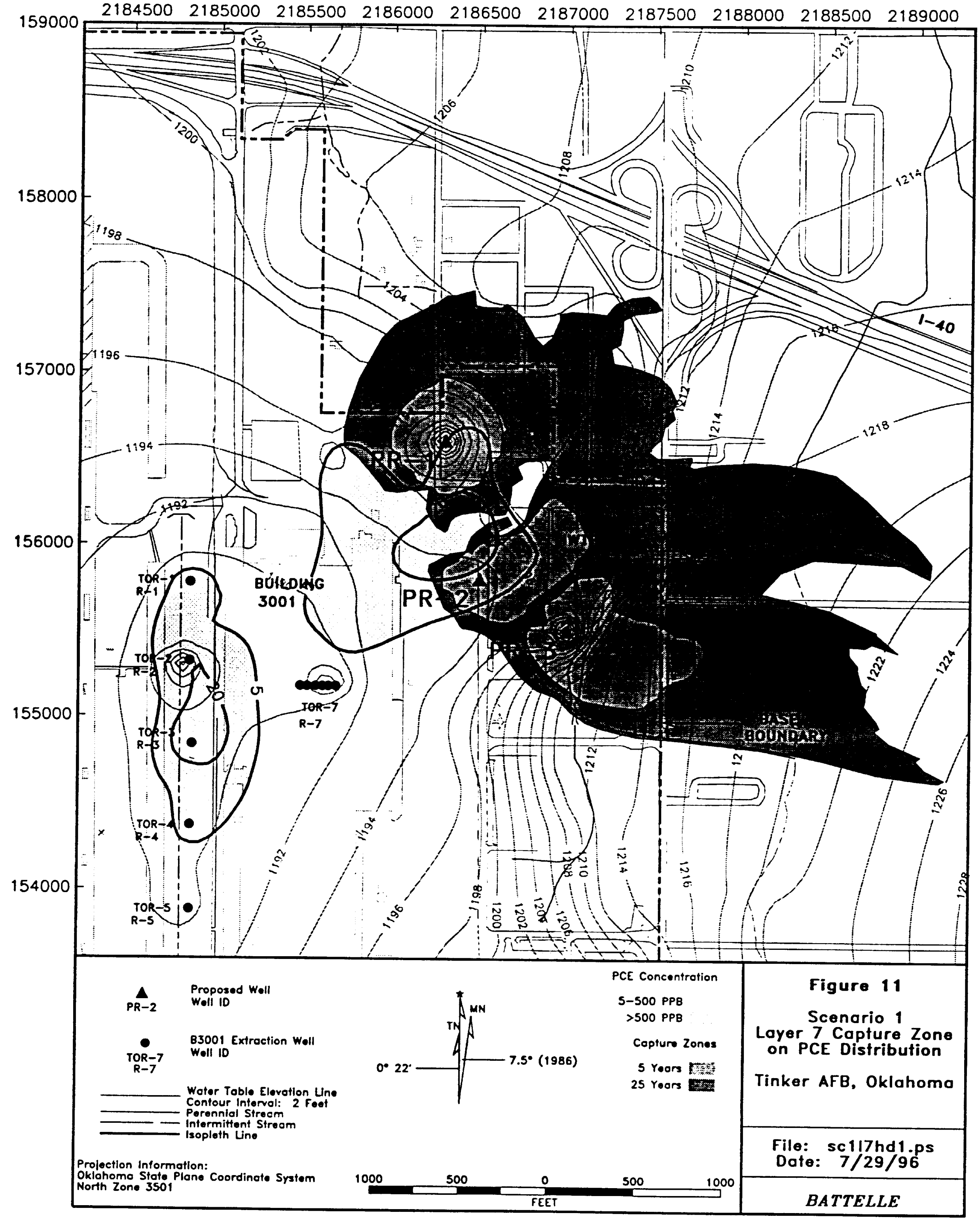


Figure 11
Scenario 1
Layer 7 Capture Zone on PCE Distribution
Tinker AFB, Oklahoma

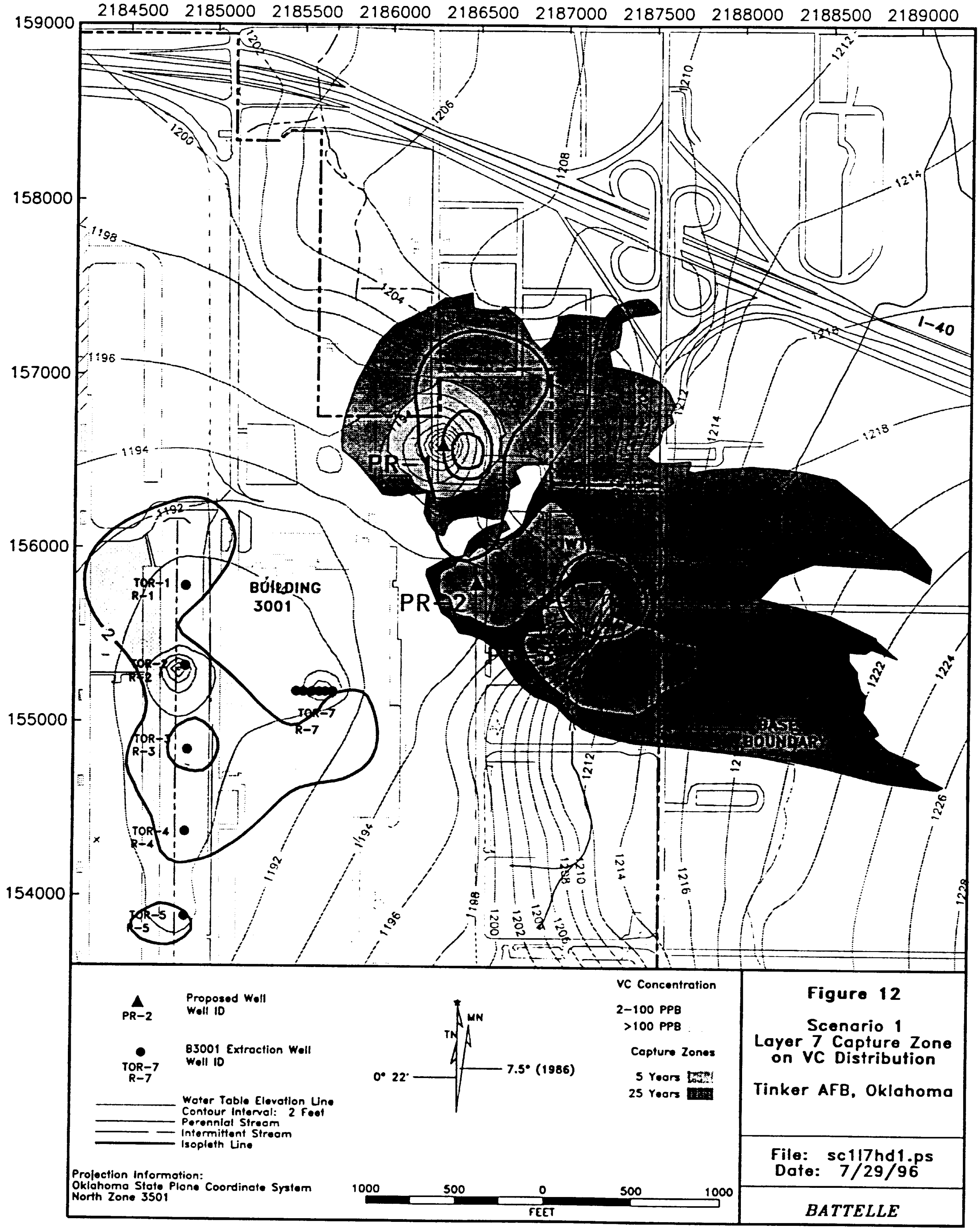


Figure 12

Scenario 1
Layer 7 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc1l7hd1.ps
Date: 7/29/96

BATTELLE

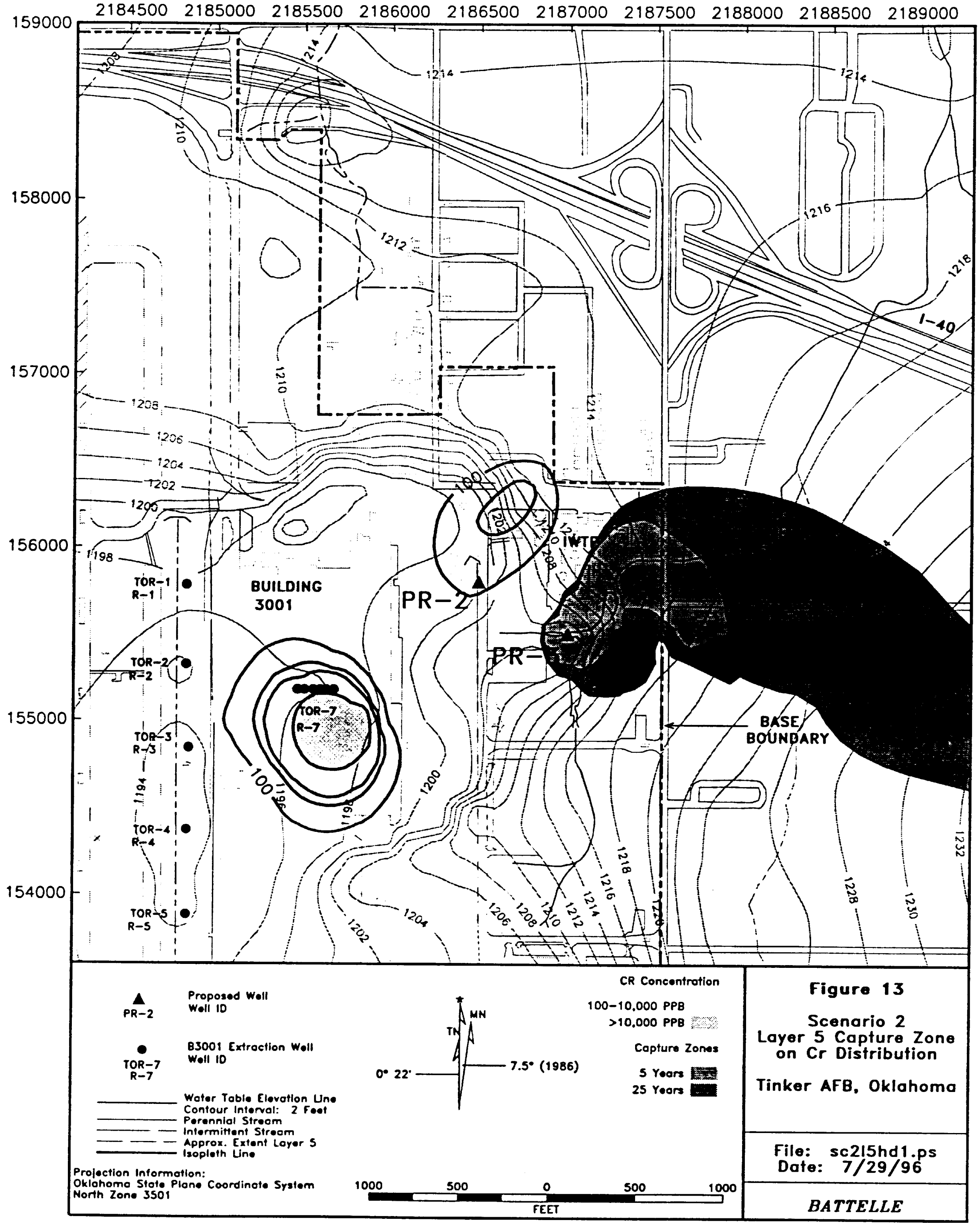


Figure 13

Scenario 2
Layer 5 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc2l5hd1.ps
Date: 7/29/96

BATTELLE

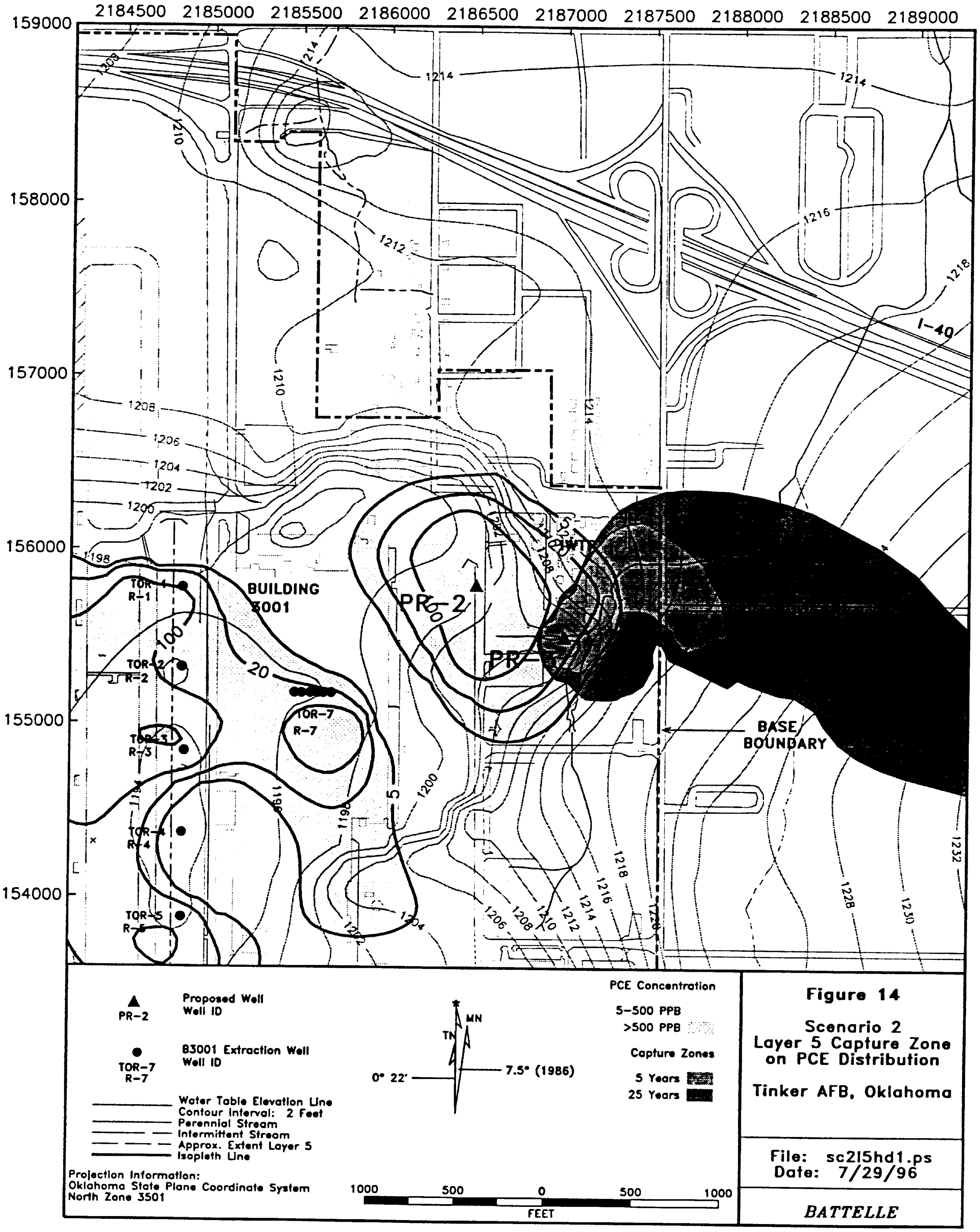


Figure 14
Scenario 2
Layer 5 Capture Zone on PCE Distribution
Tinker AFB, Oklahoma

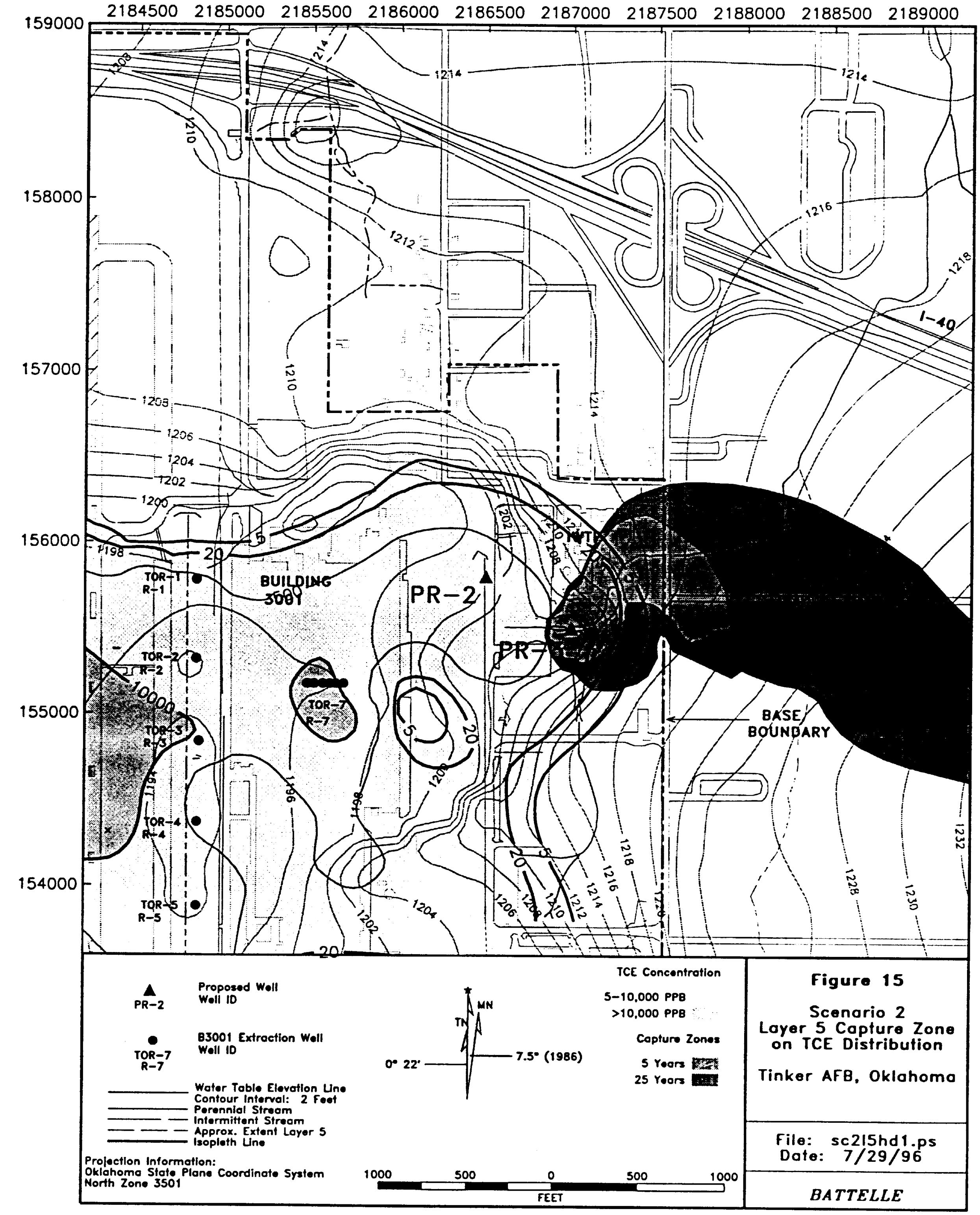


Figure 15

Scenario 2
Layer 5 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc215hd1.ps
Date: 7/29/96

BATTELLE

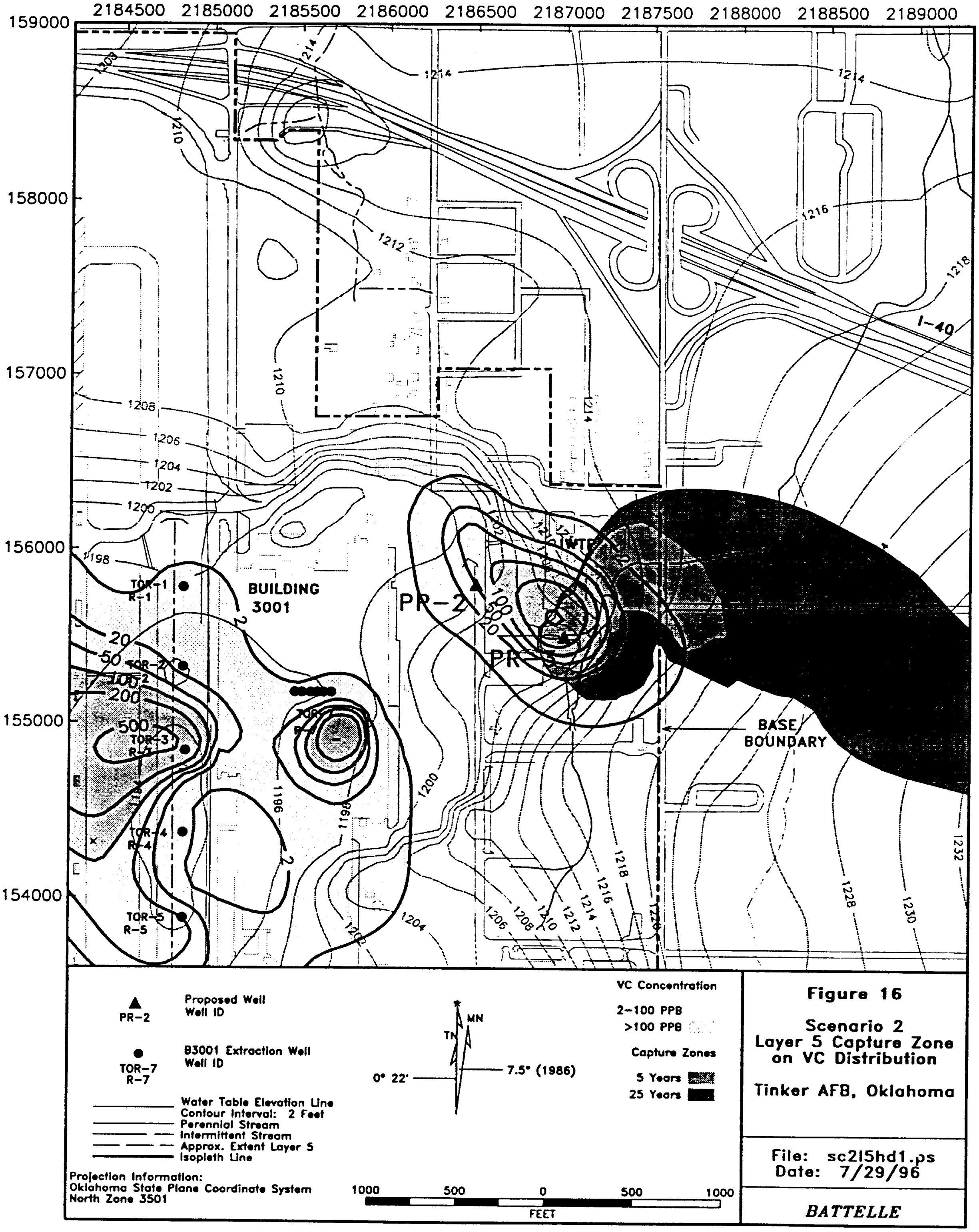


Figure 16

Scenario 2
Layer 5 Capture Zone on VC Distribution

Tinker AFB, Oklahoma

File: sc215hd1.ps
Date: 7/29/96

BATTELLE

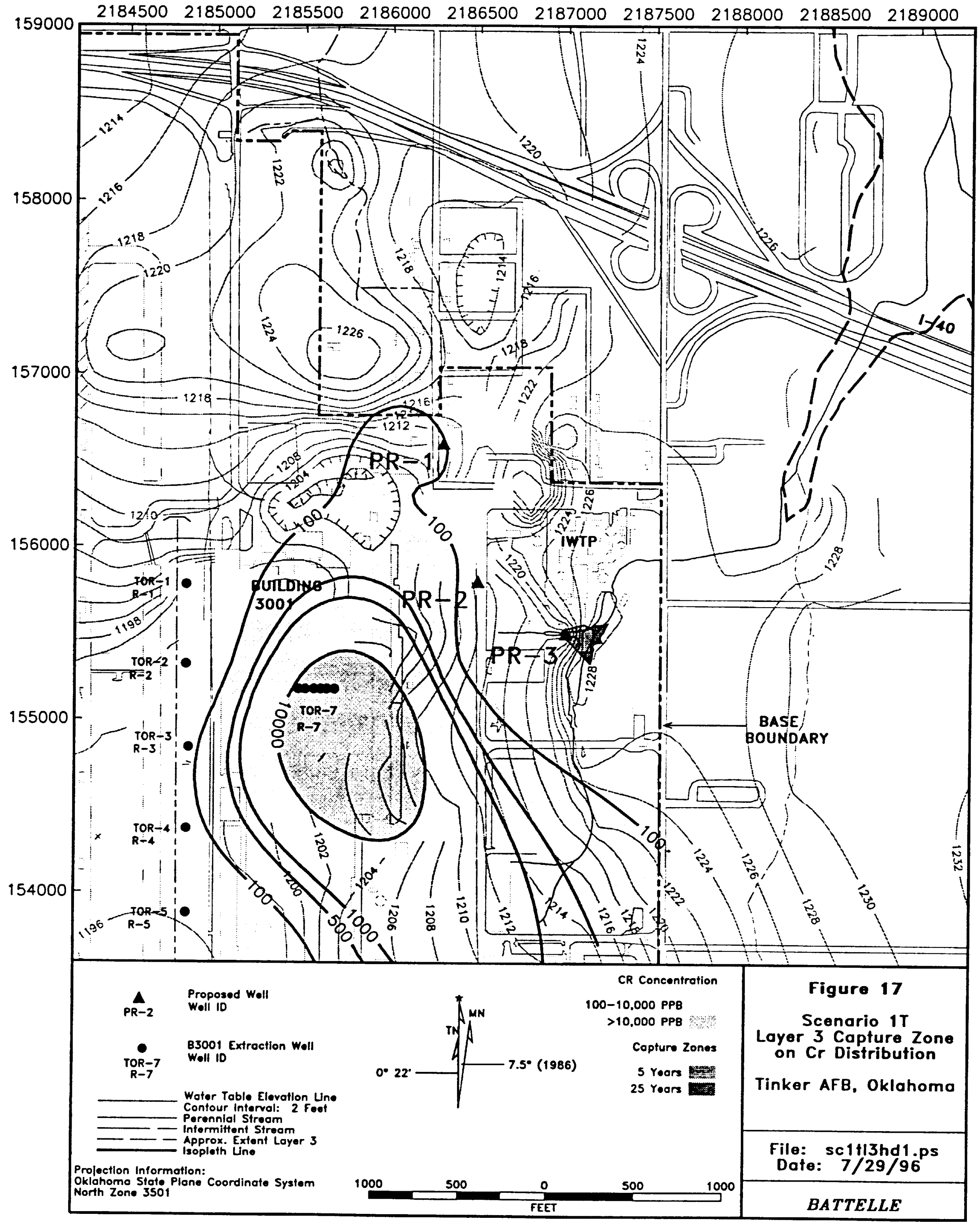


Figure 17

Scenario 1T
Layer 3 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc1tl3hd1.ps
Date: 7/29/96

BATTELLE

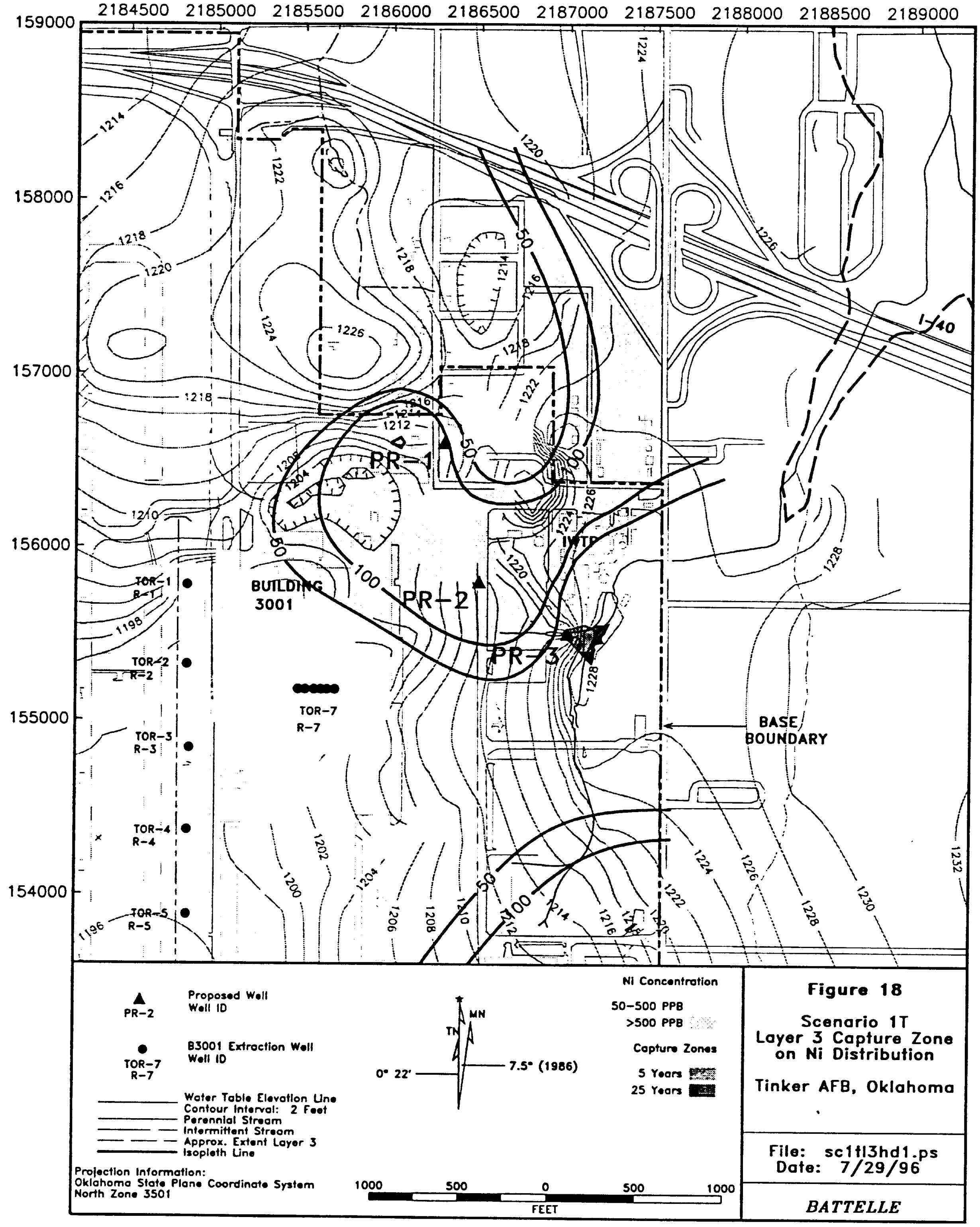


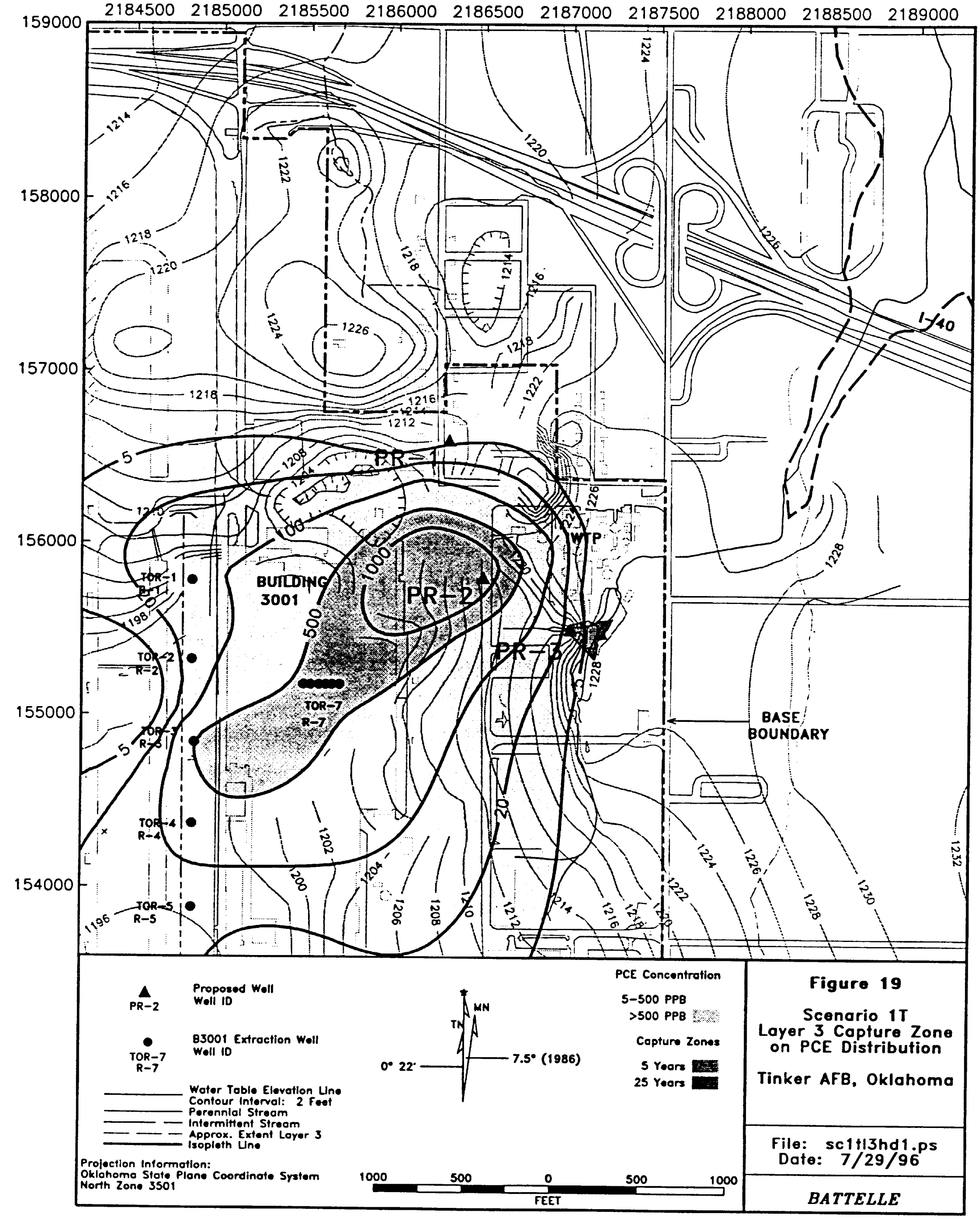
Figure 18

Scenario 1T
Layer 3 Capture Zone
on Ni Distribution

Tinker AFB, Oklahoma

File: sc1tl3hd1.ps
Date: 7/29/96

BATTELLE



2184500 2185000 2185500 2186000 2186500 2187000 2187500 2188000 2188500 2189000
159000
158000
157000
156000
155000
154000
BUILDING 3001
PR-1
PR-2
PR-3
WTP
I-40
BASE BOUNDARY
Proposed Well
Well ID
PR-2
B3001 Extraction Well
Well ID
TOR-7
R-7
Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 3
Isopleth Line
Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501
TN
MN
0° 22'
7.5° (1986)
1000 500 0 500 1000
FEET
PCE Concentration
5-500 PPB
>500 PPB
Capture Zones
5 Years
25 Years
Figure 19
Scenario 1T
Layer 3 Capture Zone
on PCE Distribution
Tinker AFB, Oklahoma
File: sc1tl3hd1.ps
Date: 7/29/96
BATTELLE

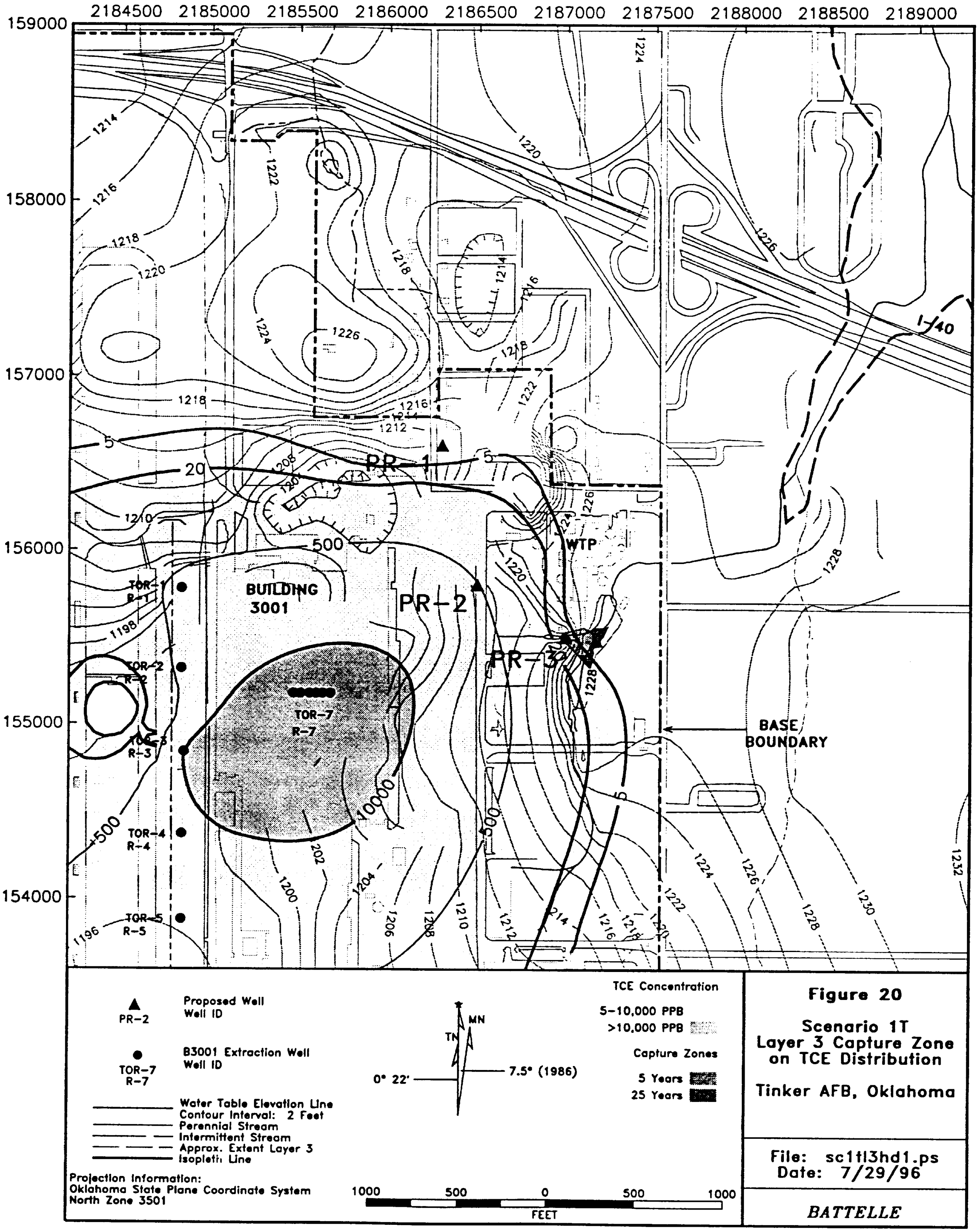


Figure 20

Scenario 1T
Layer 3 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc1tl3hd1.ps
Date: 7/29/96

BATTELLE

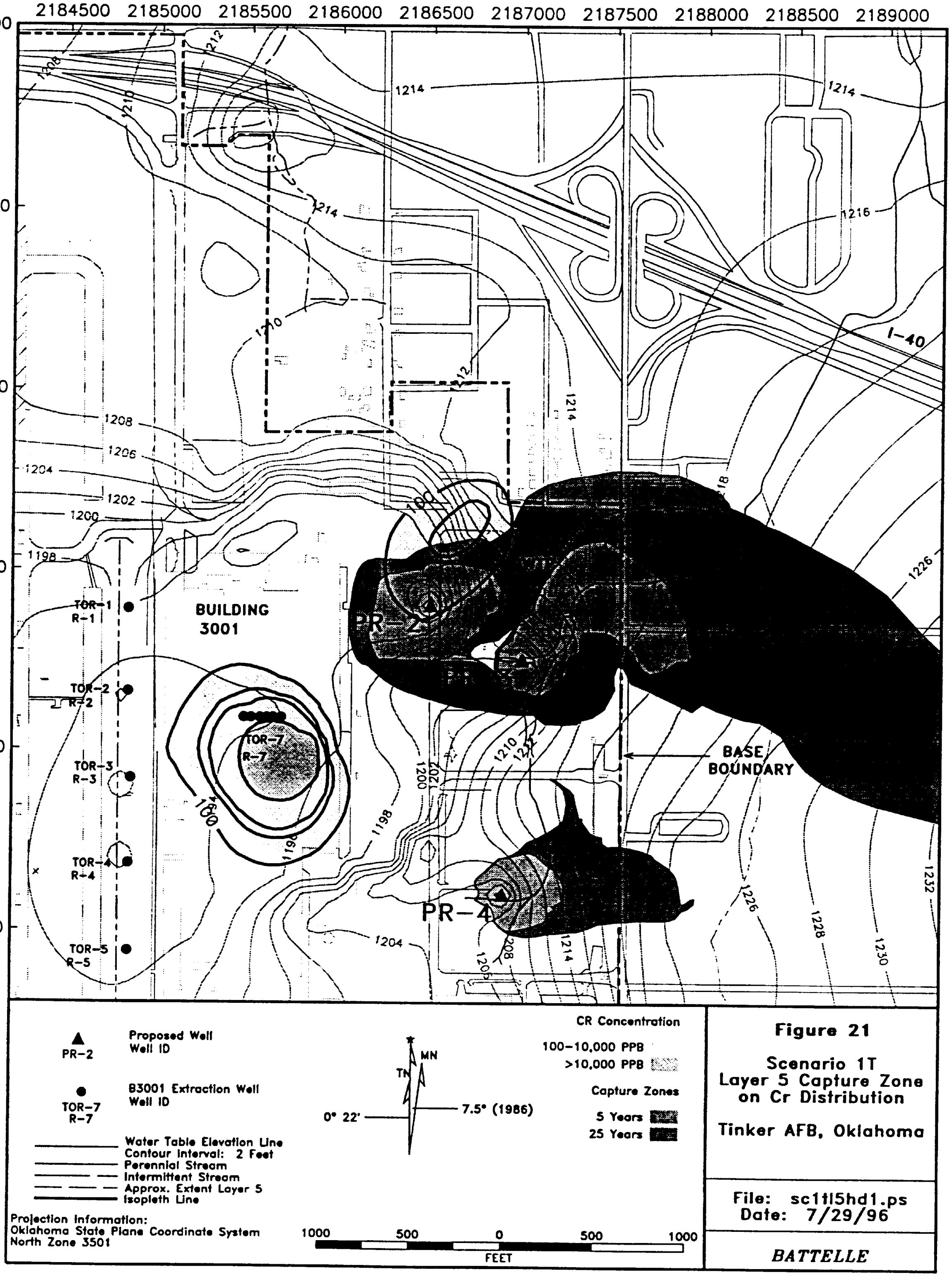


Figure 21

Scenario 1T
Layer 5 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc1tl5hd1.ps
Date: 7/29/96

BATTELLE

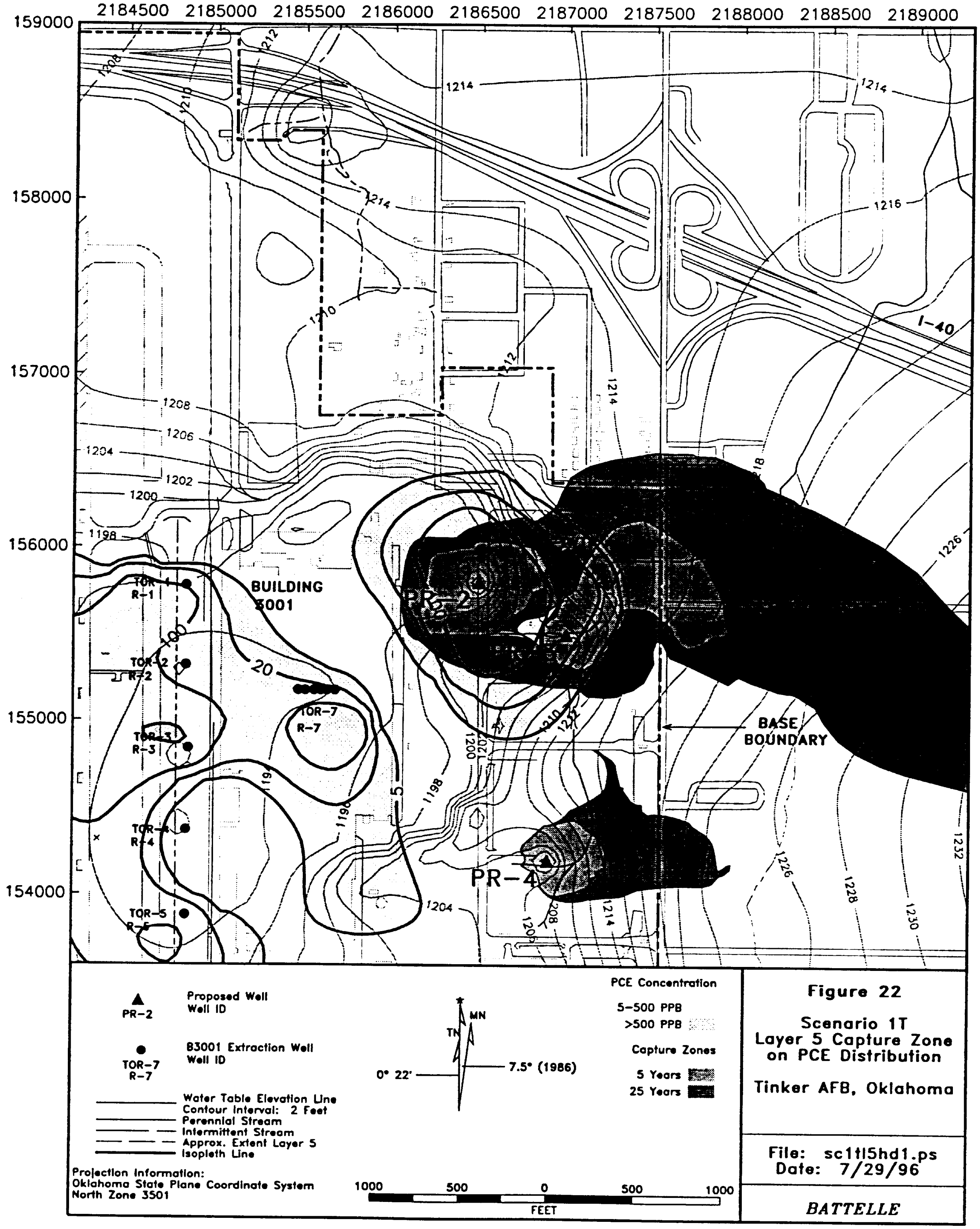


Figure 22

Scenario 1T
Layer 5 Capture Zone
on PCE Distribution

Tinker AFB, Oklahoma

File: sc1tl5hd1.ps
Date: 7/29/96

BATTELLE

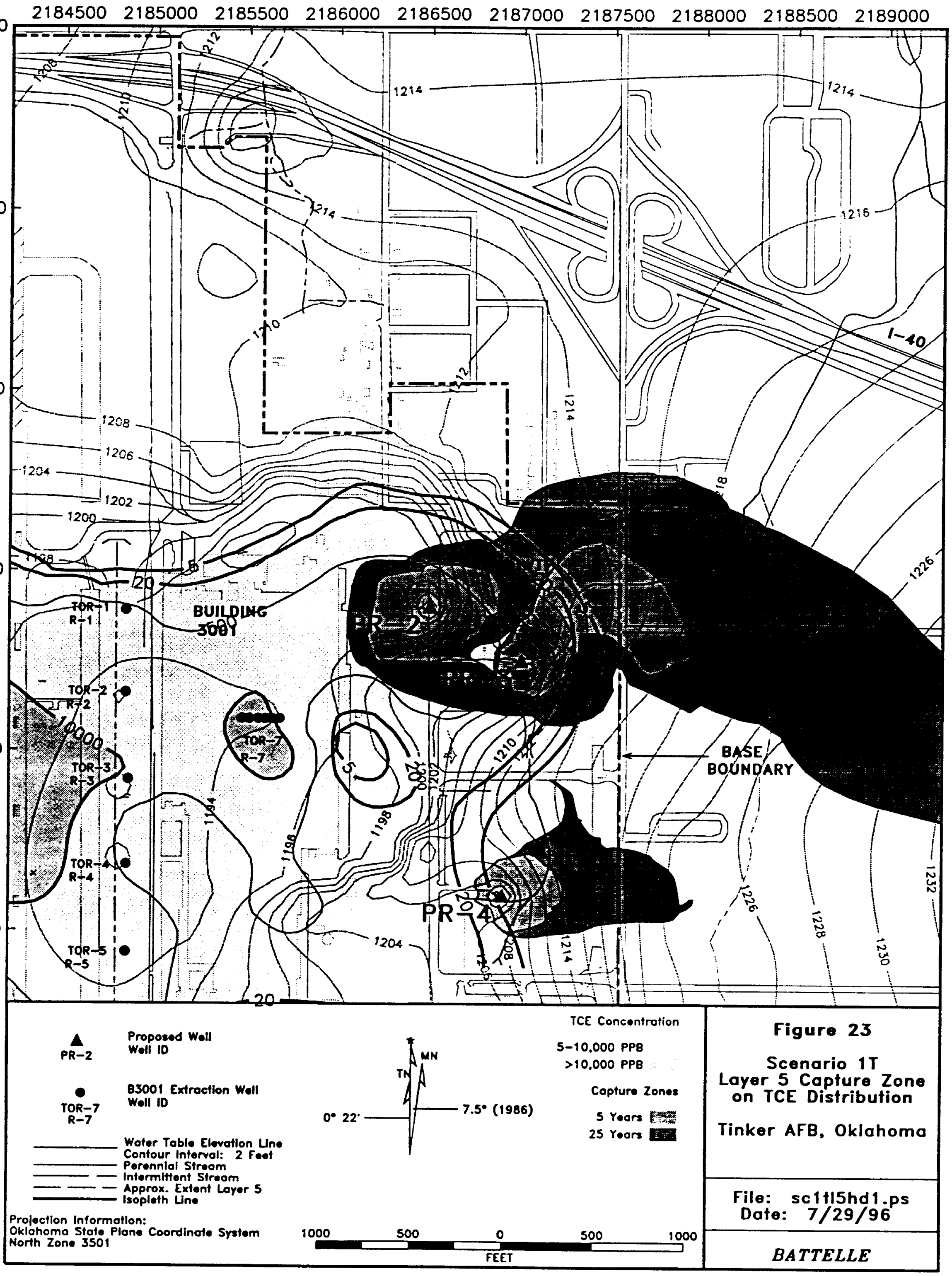


Figure 23

Scenario 1T
Layer 5 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc1t15hd1.ps
Date: 7/29/96

BATTELLE

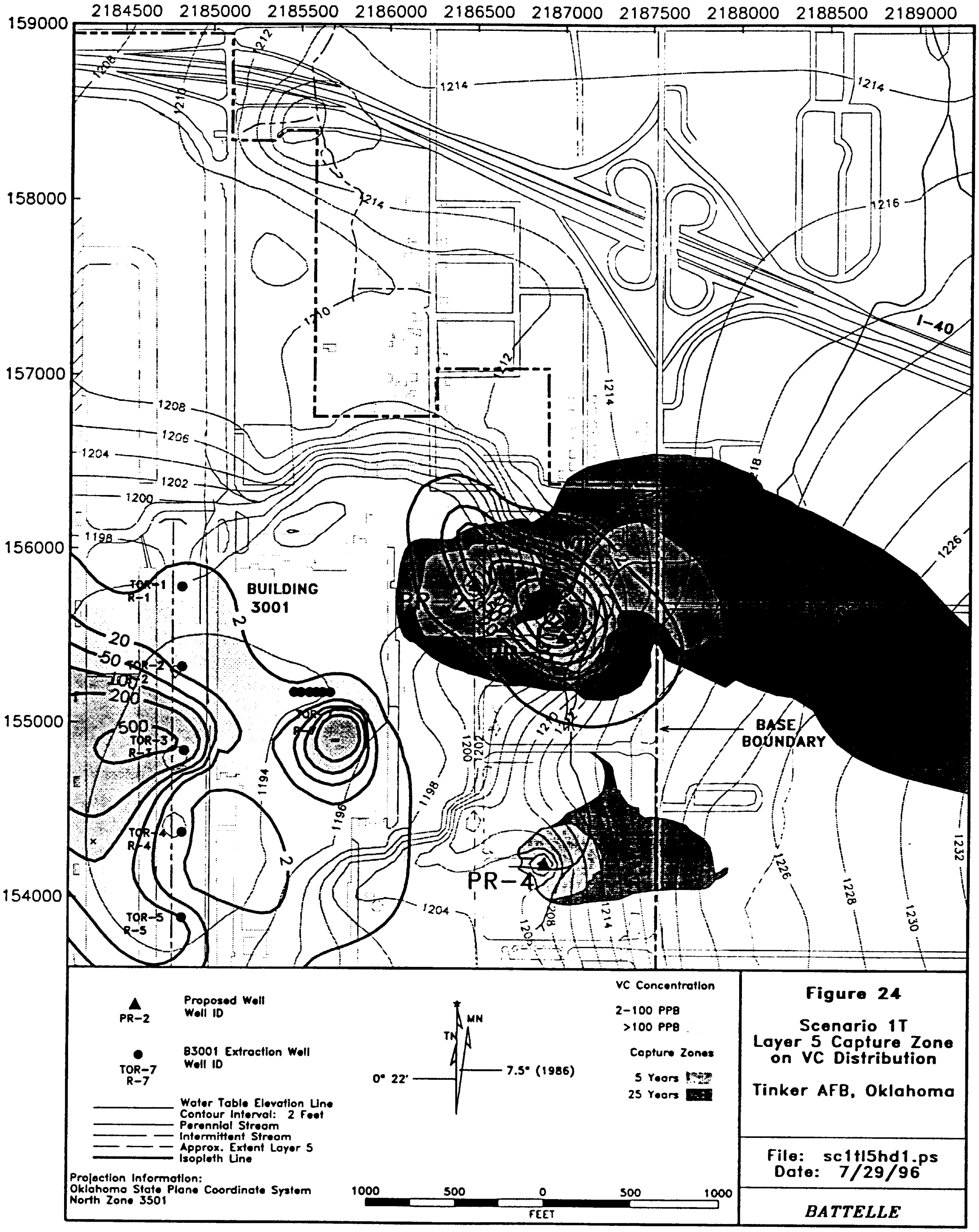


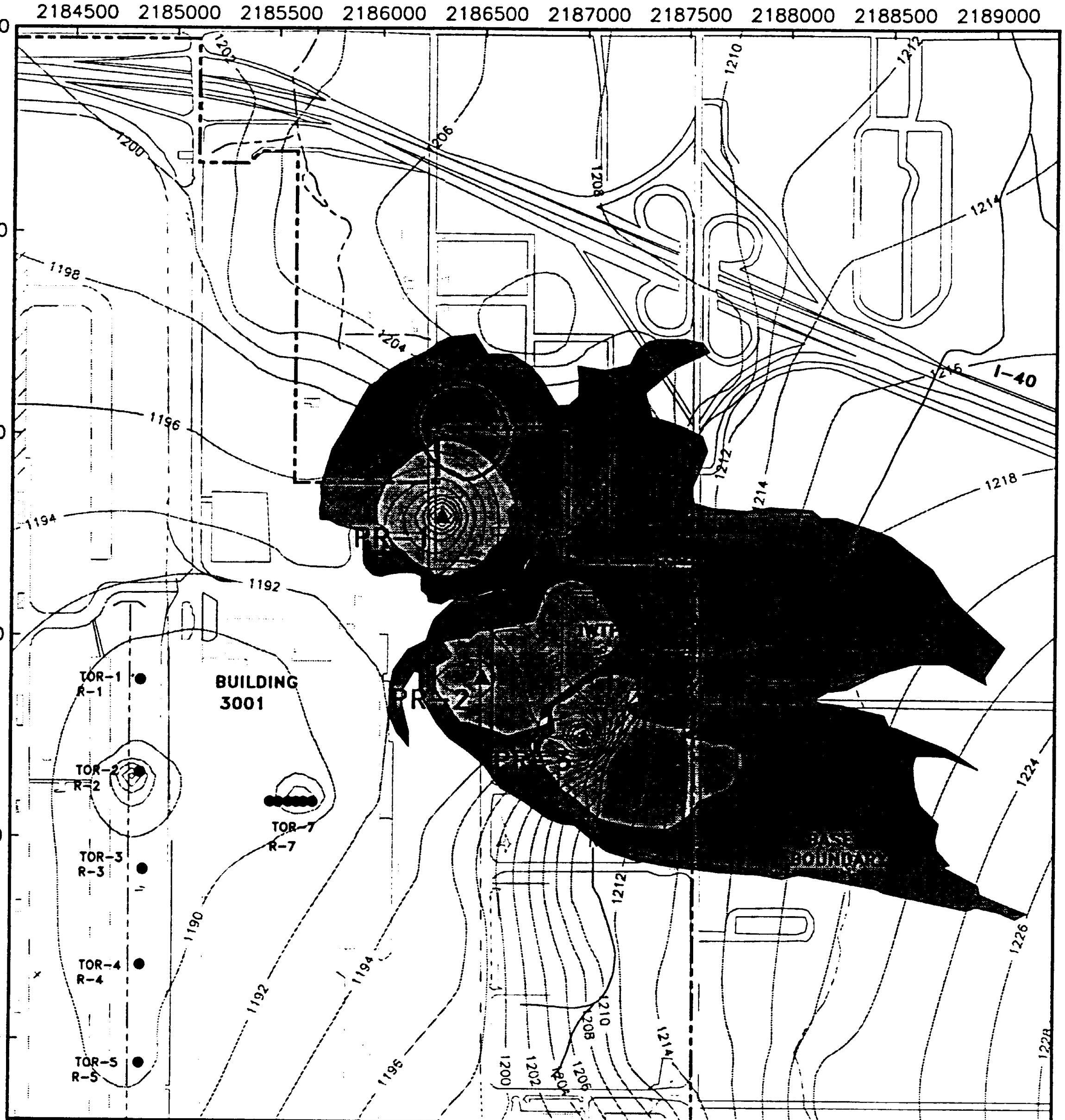
Figure 24

Scenario 1T
Layer 5 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc1t15hd1.ps
Date: 7/29/96

BATTELLE



Proposed Well
PR-2 Well ID

B3001 Extraction Well
TOR-7 R-7 Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Isopleth Line

TN MN
0° 22'
7.5° (1986)

CR Concentration
100–10,000 PPB
>10,000 PPB

Capture Zones
5 Years
25 Years

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

1000 500 0 500 1000
FEET

Figure 25

Scenario 1T
Layer 7 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc1tl7hd1.ps
Date: 7/29/96

BATTELLE

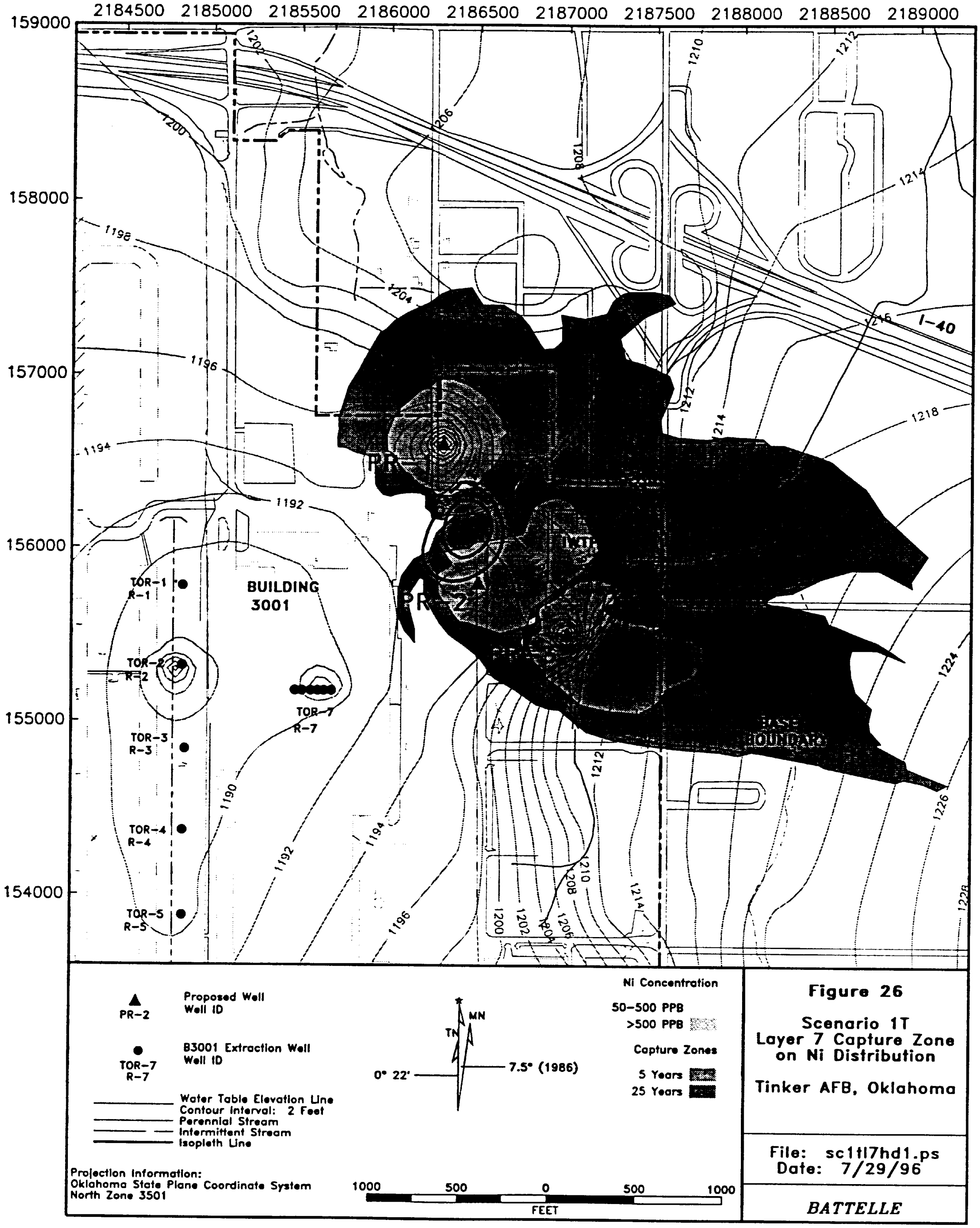


Figure 26
Scenario 1T
Layer 7 Capture Zone
on Ni Distribution

Tinker AFB, Oklahoma

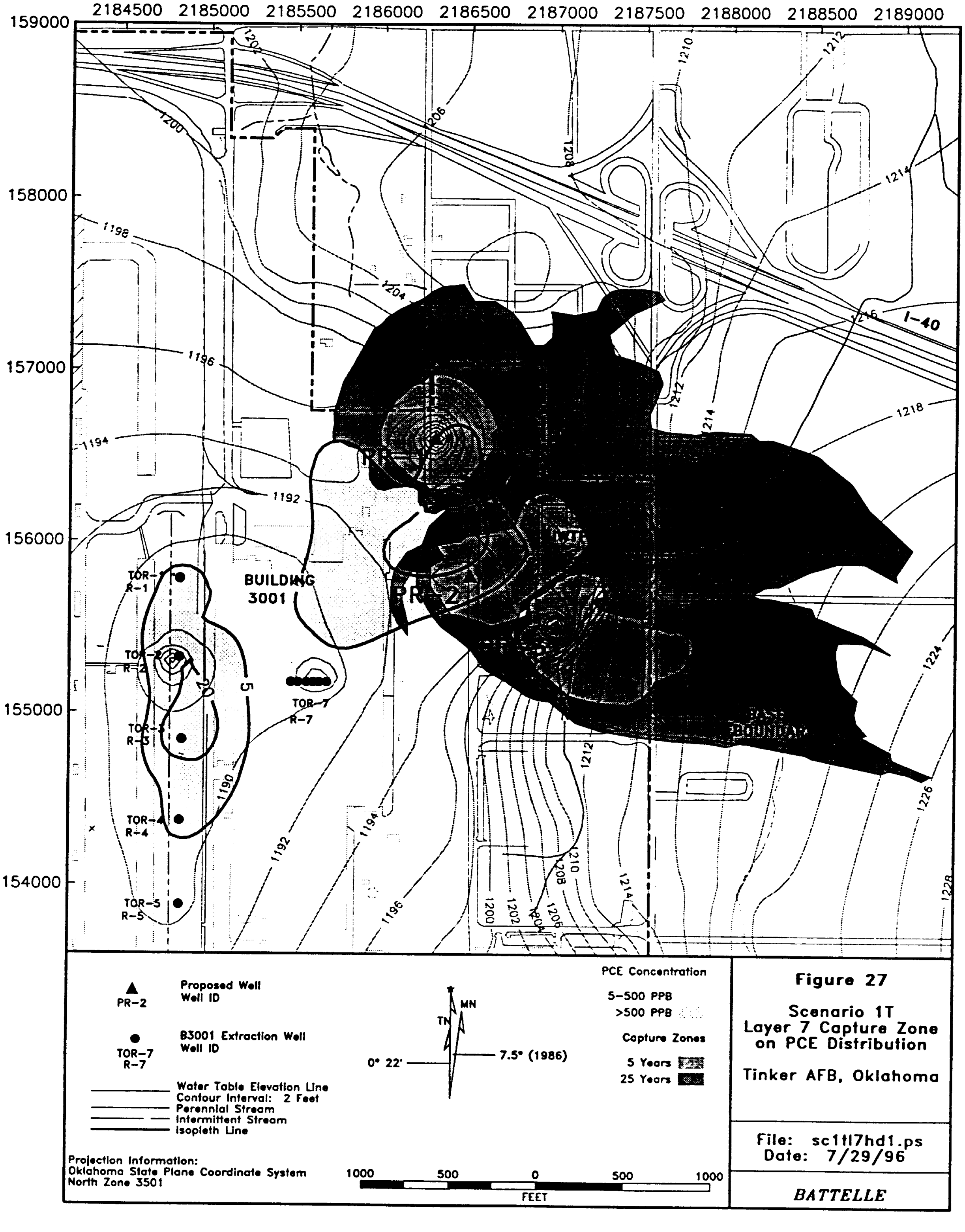


Figure 27
Scenario 1T
Layer 7 Capture Zone
on PCE Distribution
Tinker AFB, Oklahoma

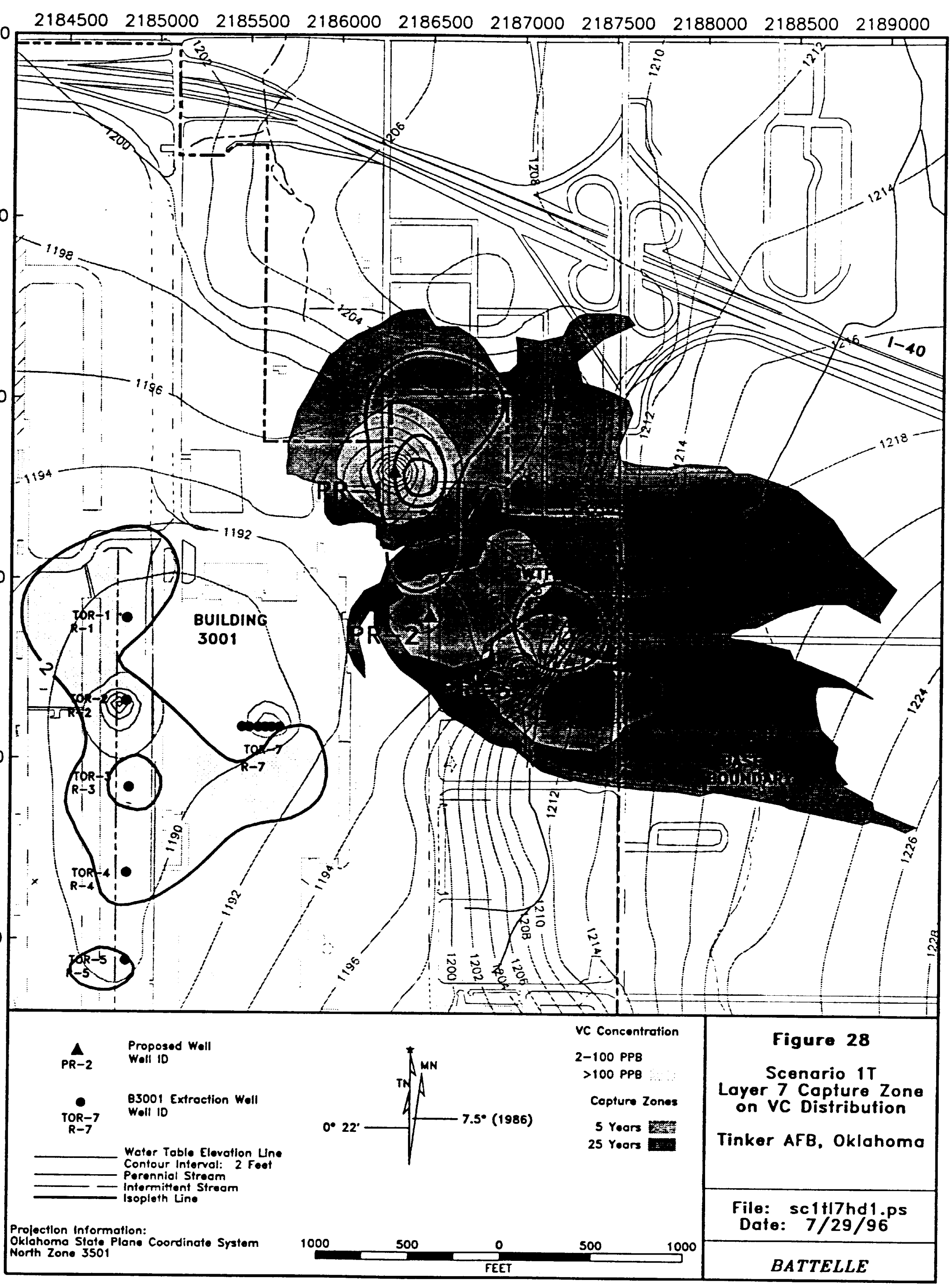


Figure 28

Scenario 1T
Layer 7 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc1tl7hd1.ps
Date: 7/29/96

BATTELLE

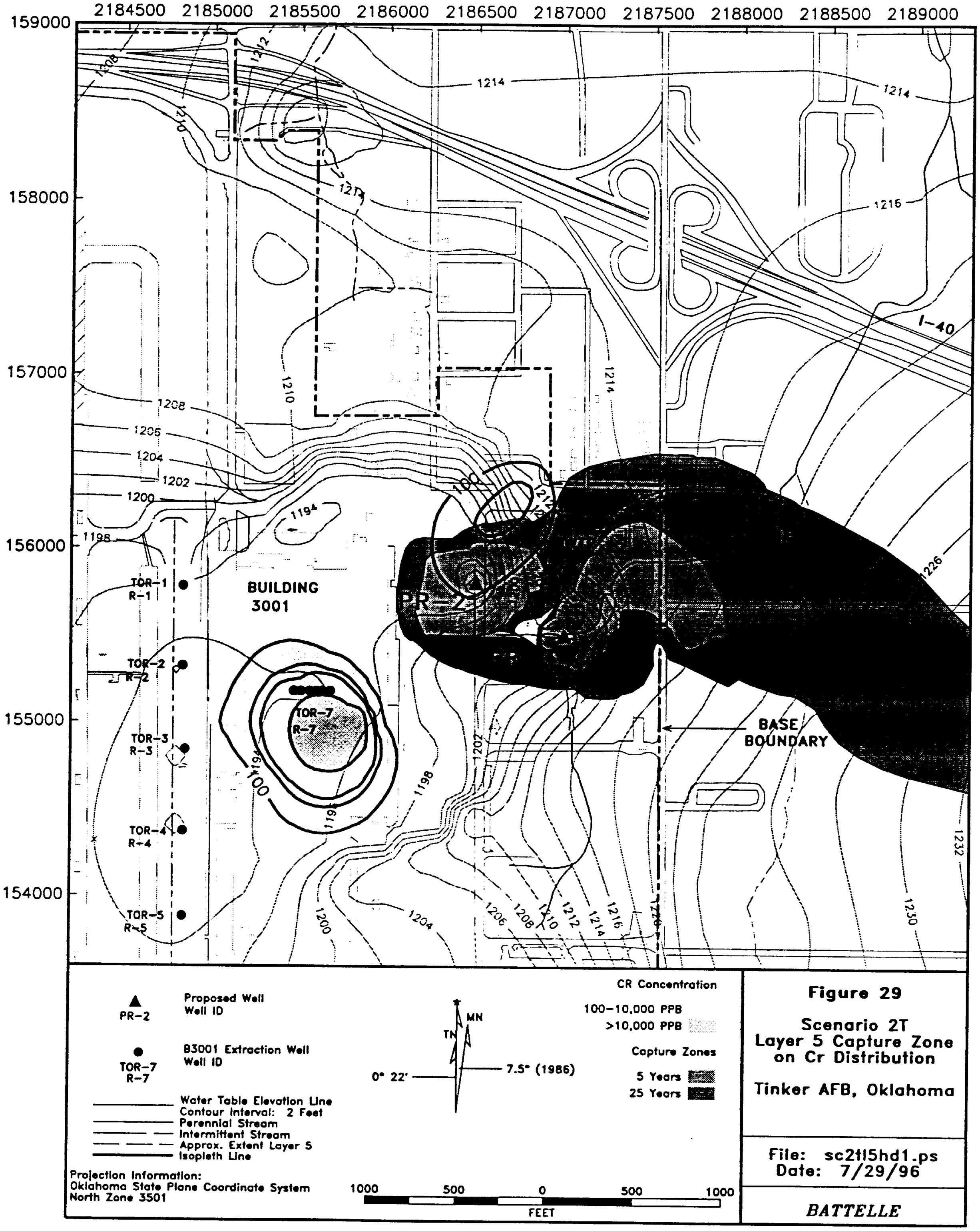


Figure 29

Scenario 2T
Layer 5 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

File: sc2tl5hd1.ps
Date: 7/29/96

BATTELLE

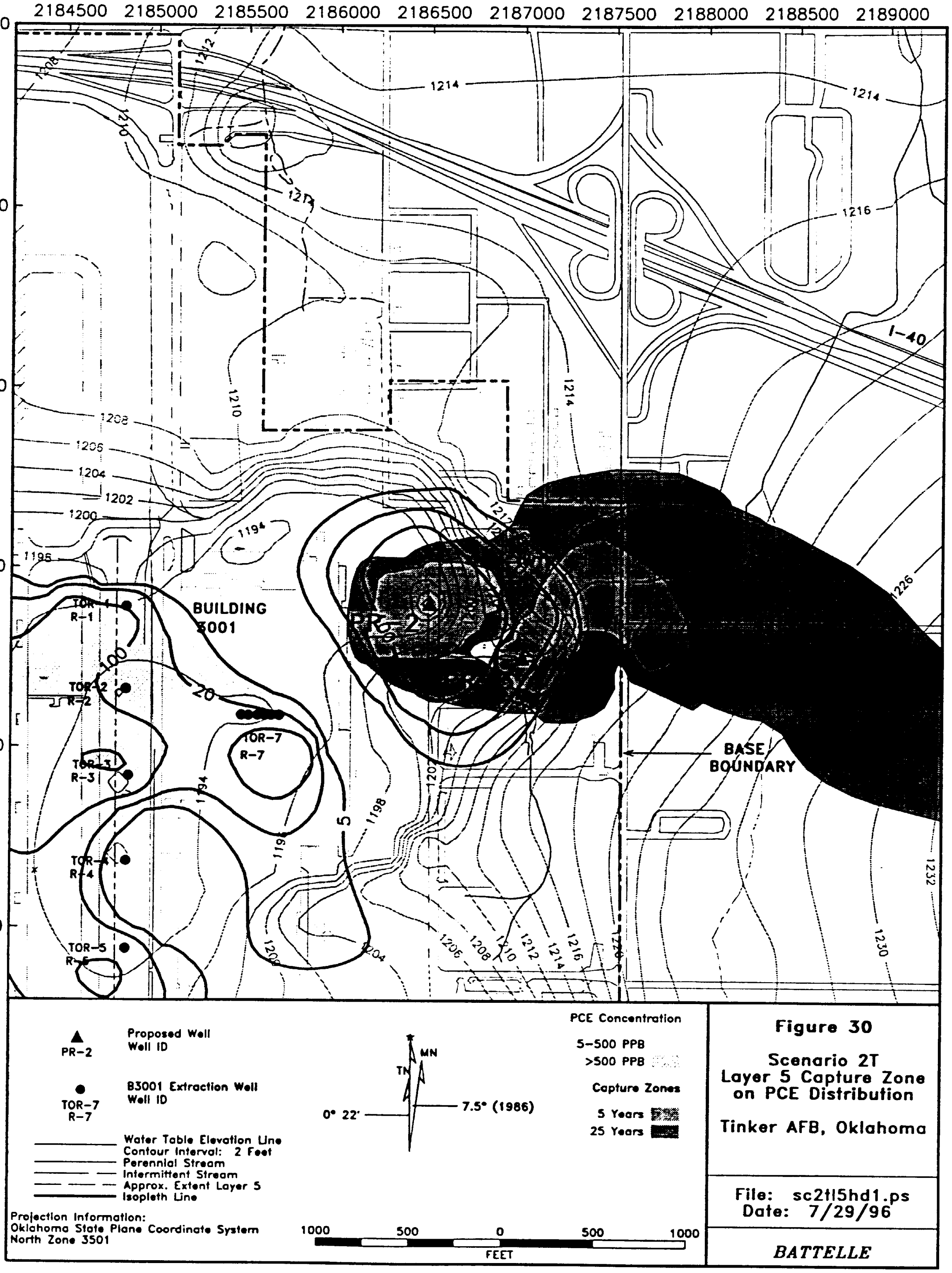


Figure 30

Scenario 2T
Layer 5 Capture Zone
on PCE Distribution

Tinker AFB, Oklahoma

File: sc2tl5hd1.ps
Date: 7/29/96

BATTELLE

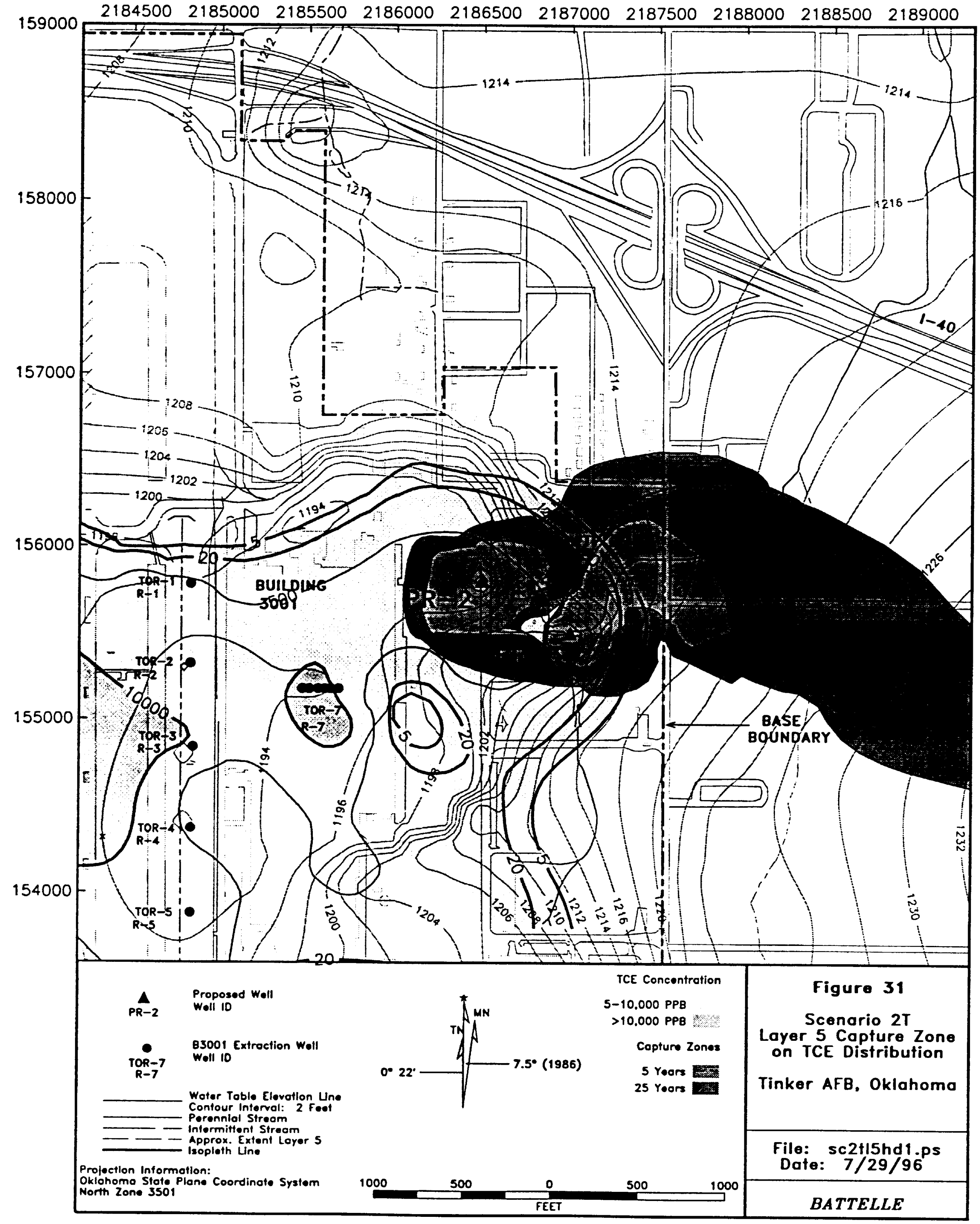


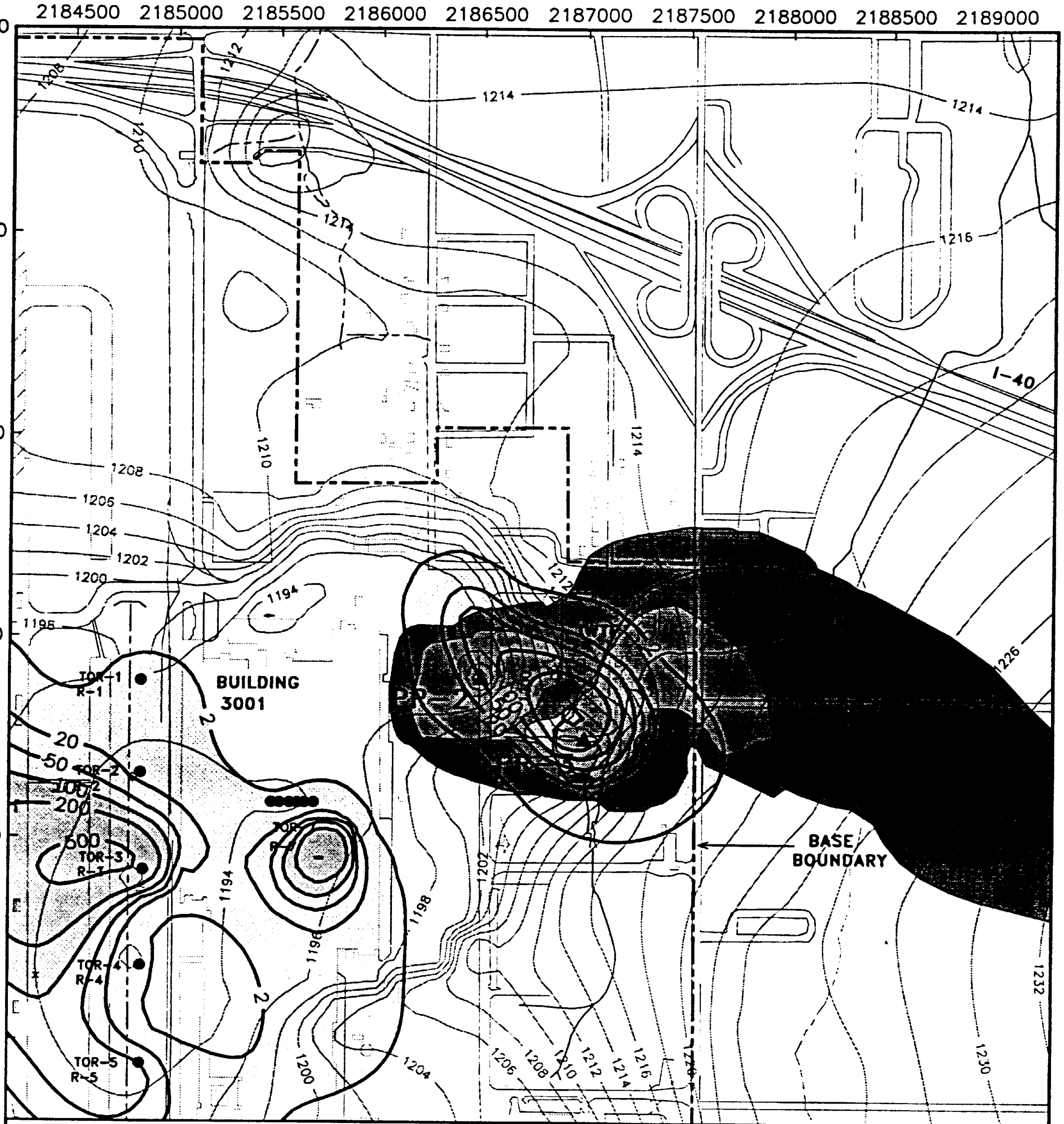
Figure 31

Scenario 2T
Layer 5 Capture Zone
on TCE Distribution

Tinker AFB, Oklahoma

File: sc2tl5hd1.ps
Date: 7/29/96

BATTELLE



VC Concentration
2-100 PPB
>100 PPB

Capture Zones
5 Years
25 Years

▲ PR-2 — Proposed Well, Well ID

● TOR-7 R-7 — B3001 Extraction Well, Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 5
Isopleth Line

TN MN
0° 22'
7.5° (1986)

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

1000 500 0 500 1000
FEET

Figure 32

Scenario 2T
Layer 5 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc2tl5hd1.ps
Date: 7/29/96

BATTELLE

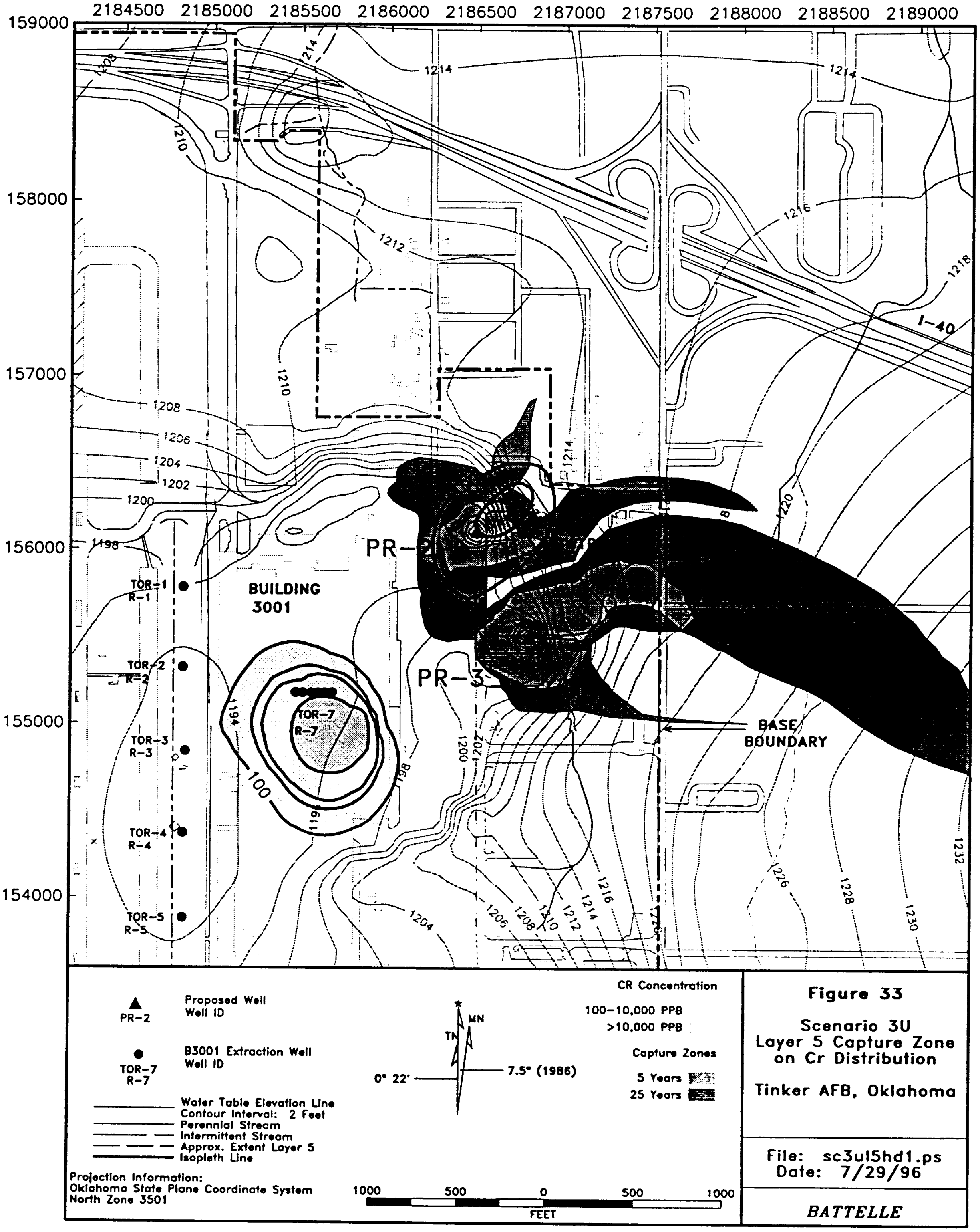


Figure 33

Scenario 3U
Layer 5 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

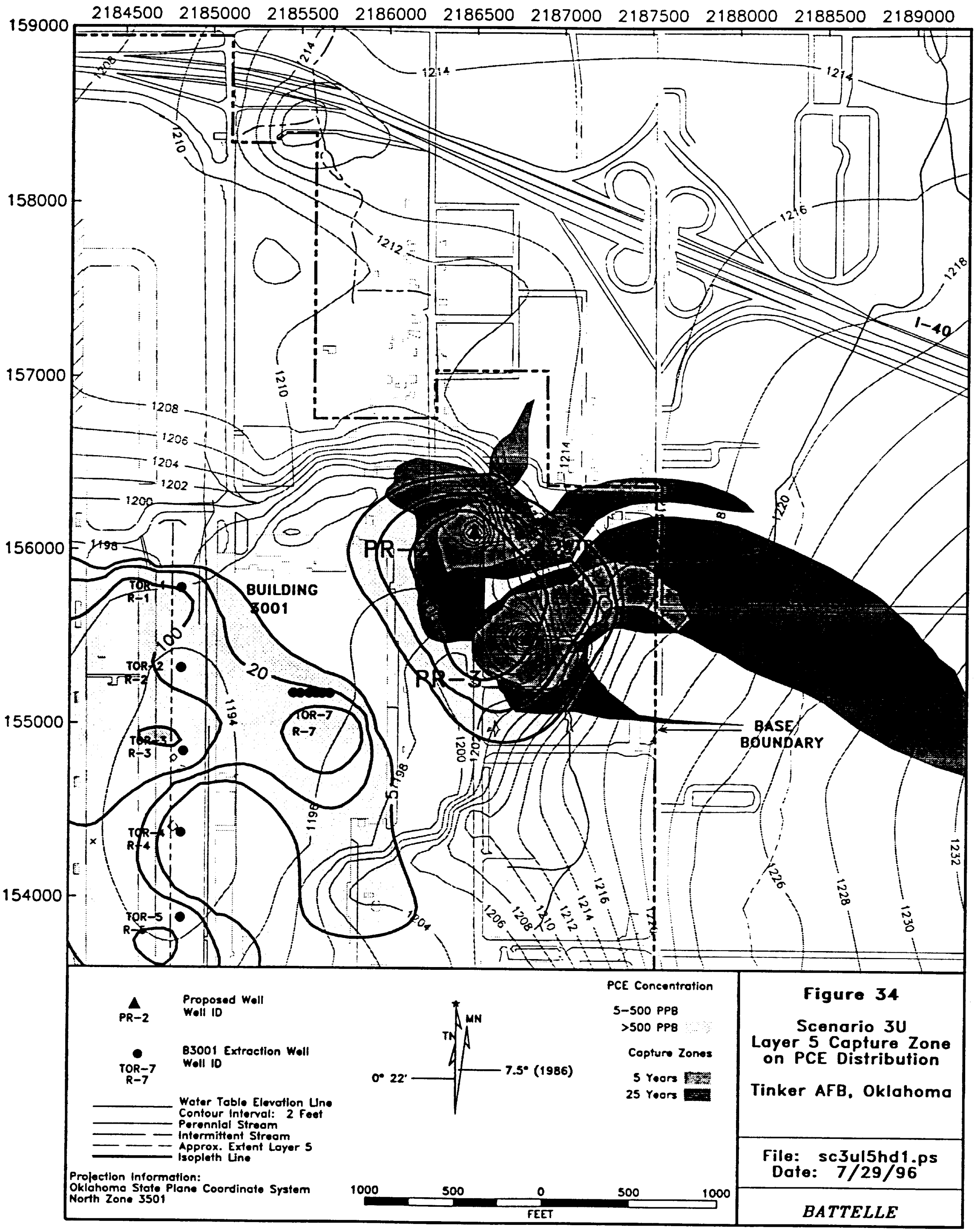


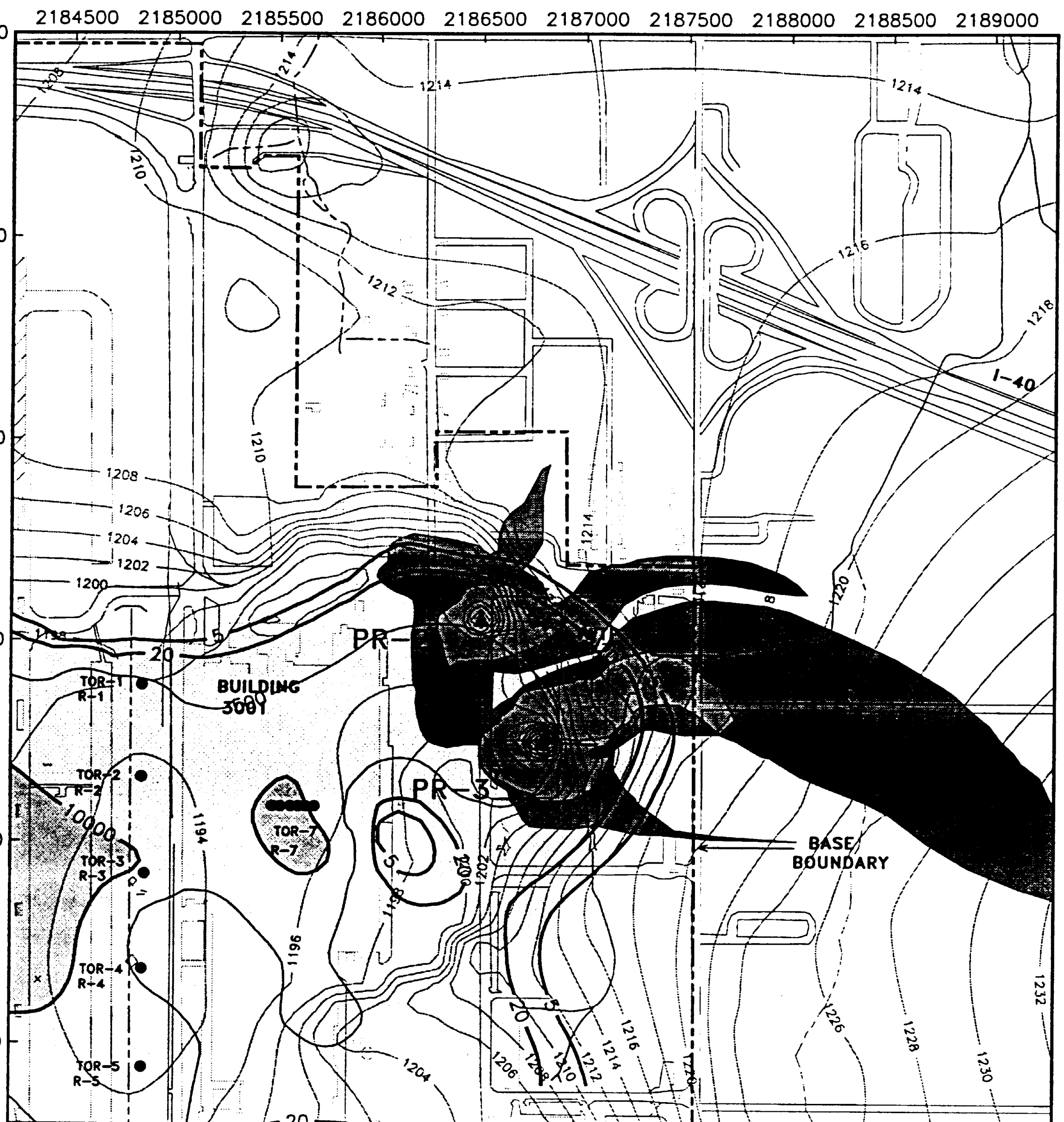
Figure 34

Scenario 3U
Layer 5 Capture Zone
on PCE Distribution

Tinker AFB, Oklahoma

File: sc3ul5hd1.ps
Date: 7/29/96

BATTELLE



Proposed Well
PR-2 Well ID

B3001 Extraction Well
TOR-7 R-7 Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 5
Isopleth Line

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

TN MN
0° 22'
7.5° (1986)

1000 500 0 500 1000
FEET

TCE Concentration
5–10,000 PPB
>10,000 PPB

Capture Zones
5 Years
25 Years

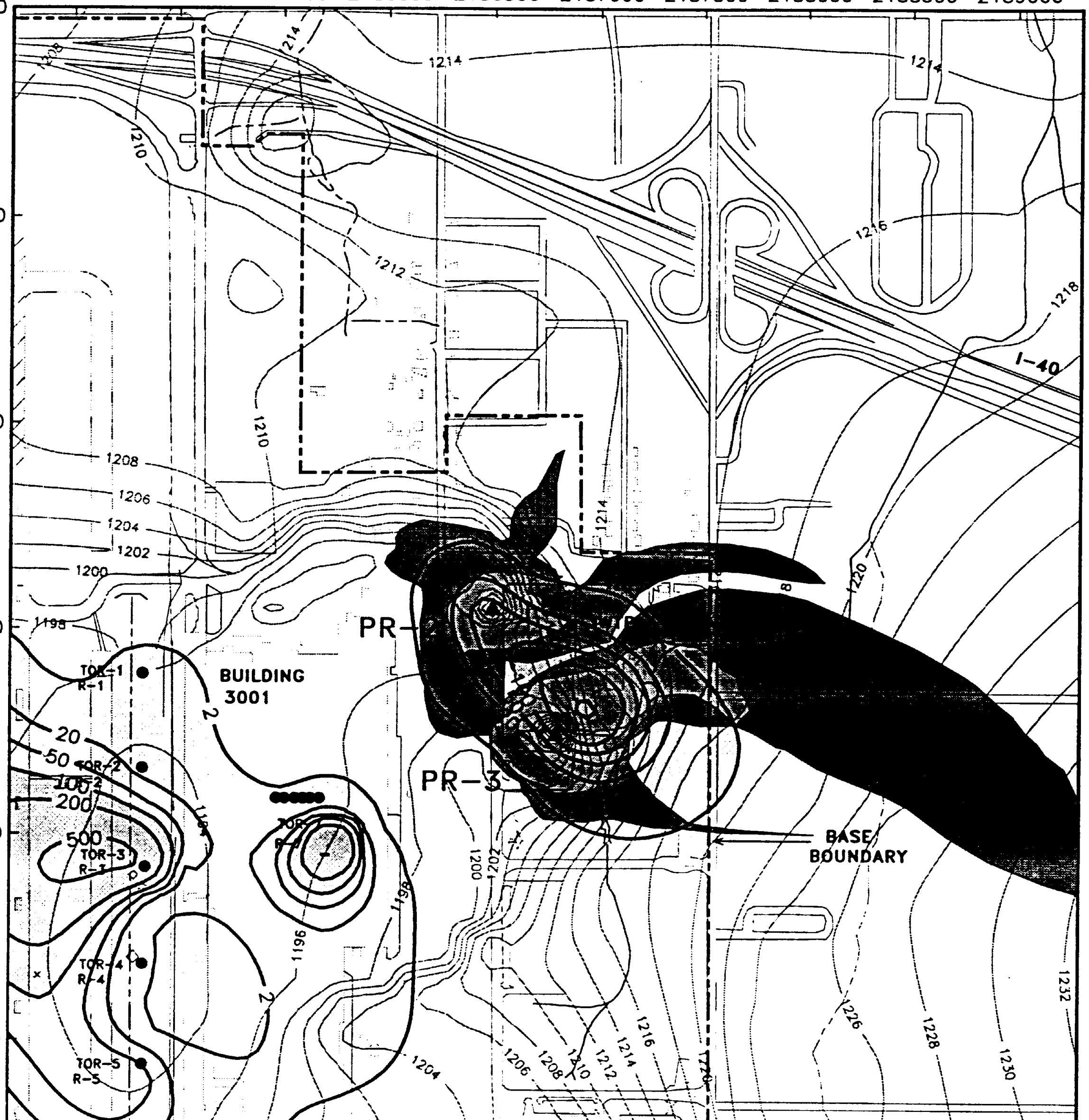
Figure 35

Scenario 3U
Layer 5 Capture Zone on TCE Distribution

Tinker AFB, Oklahoma

File: sc3ul5hd1.ps
Date: 7/29/96

BATTELLE



Proposed Well PR-2 Well ID

B3001 Extraction Well TOR-7 R-7 Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 5
Isopleth Line

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

MN TN 0° 22' 7.5° (1986)

1000 500 0 500 1000
FEET

VC Concentration
2-100 PPB
>100 PPB

Capture Zones
5 Years
25 Years

Figure 36

Scenario 3U
Layer 5 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma

File: sc3ul5hd1.ps
Date: 7/29/96

BATTELLE

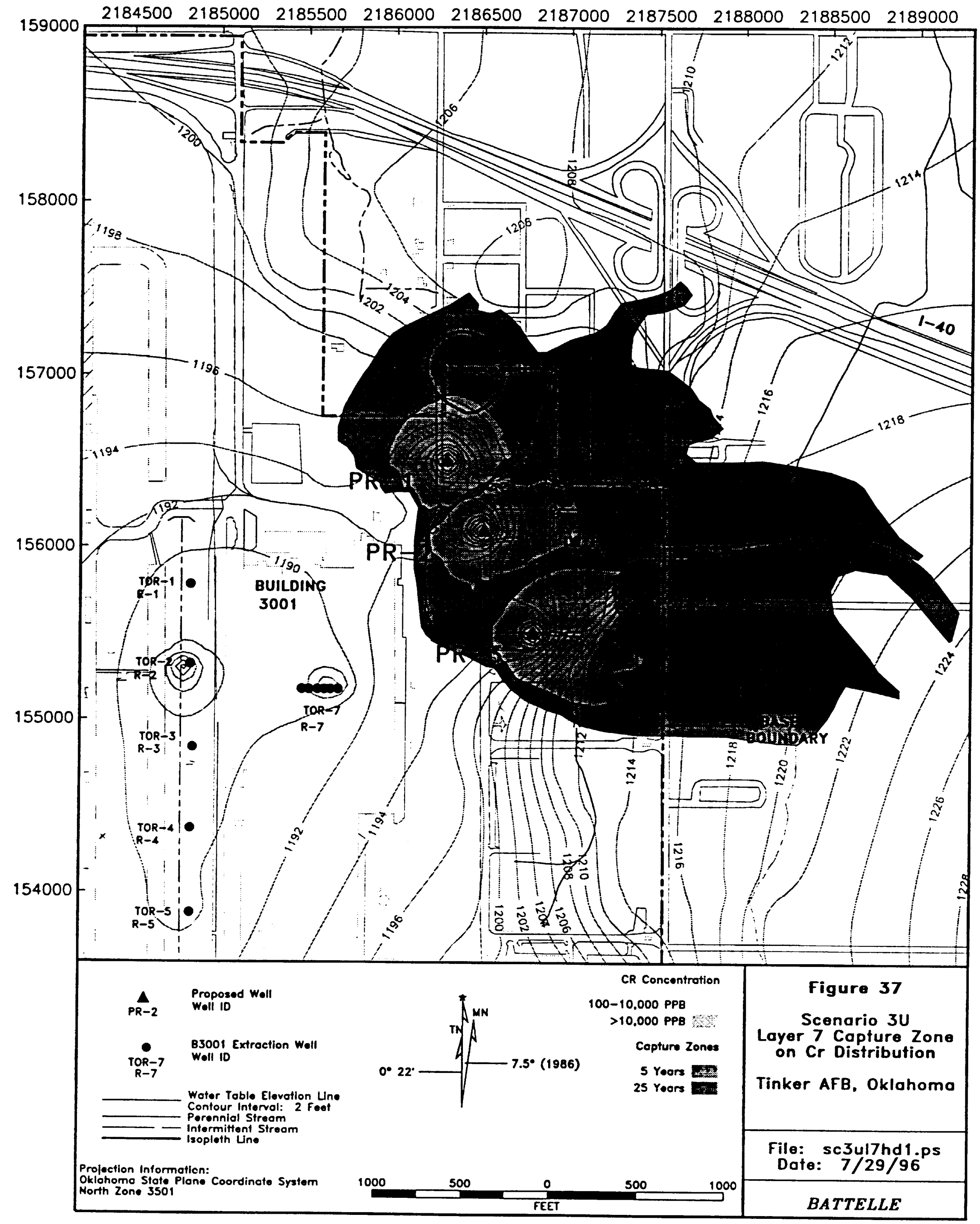


Figure 37

Scenario 3U
Layer 7 Capture Zone
on Cr Distribution

Tinker AFB, Oklahoma

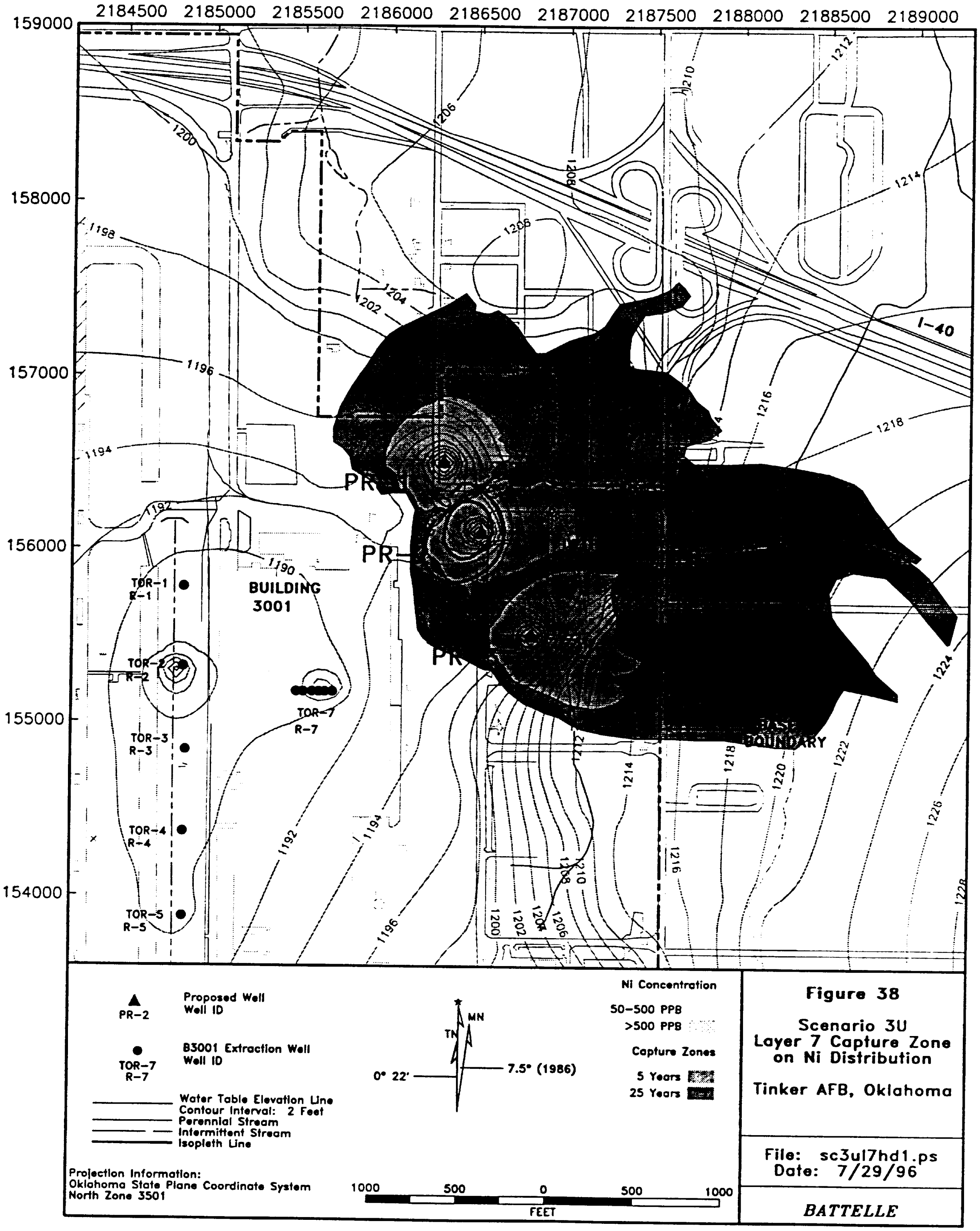


Figure 38

Scenario 3U
Layer 7 Capture Zone
on Ni Distribution

Tinker AFB, Oklahoma

File: sc3ul7hd1.ps
Date: 7/29/96

BATTELLE

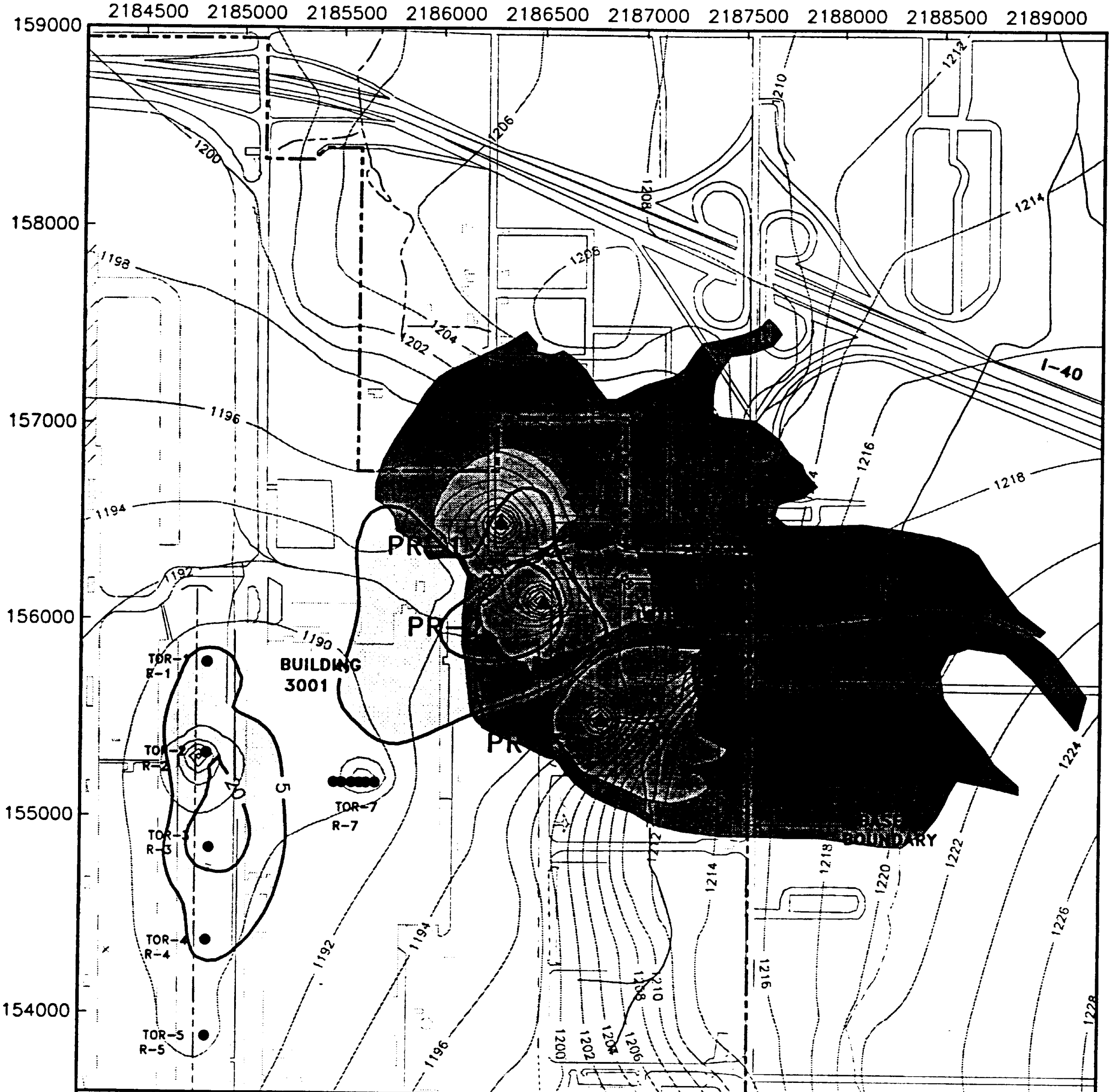


Figure 39

Scenario 3U
Layer 7 Capture Zone on PCE Distribution

Tinker AFB, Oklahoma

File: sc3ul7hd1.ps
Date: 7/29/96

BATTELLE

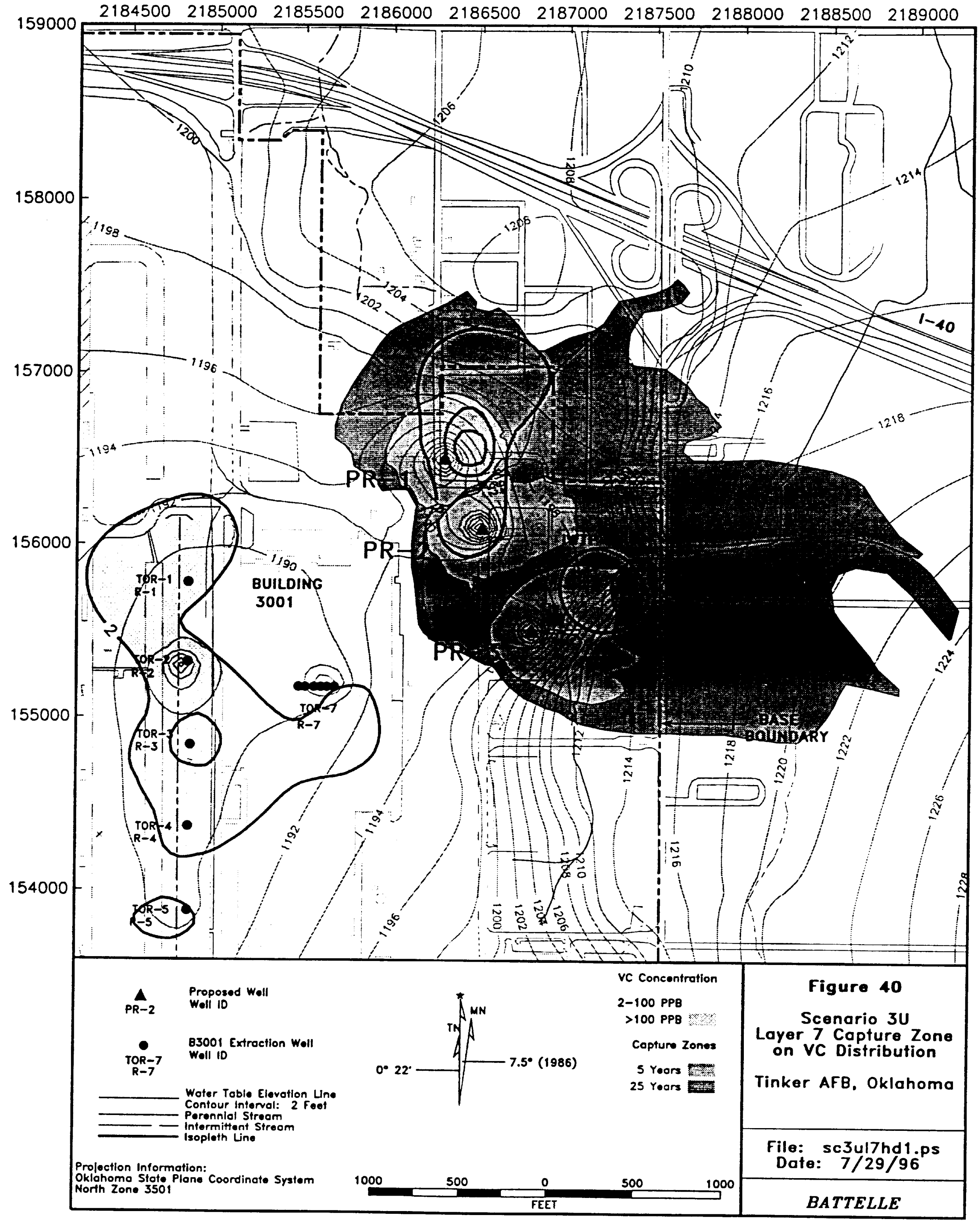
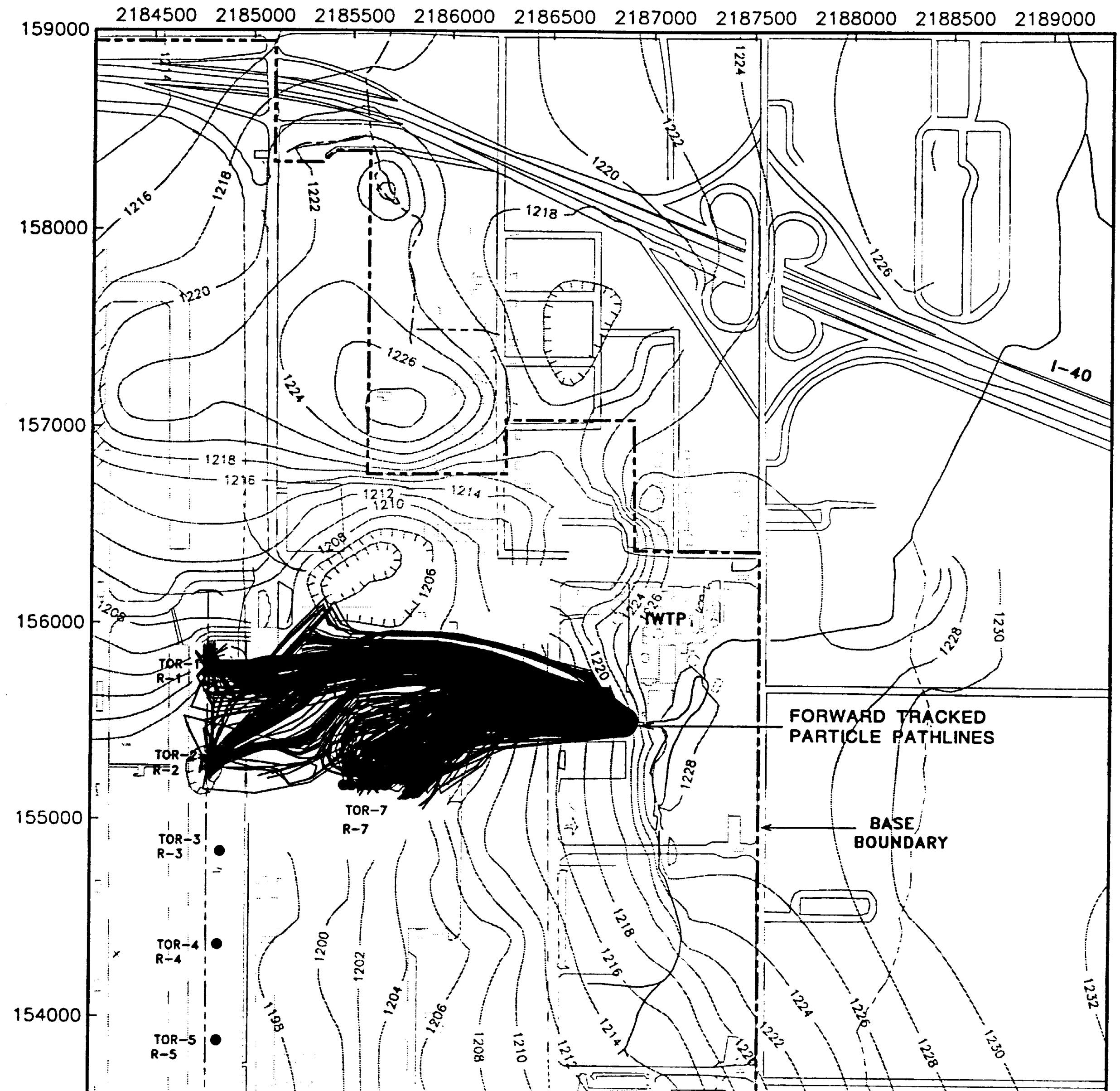


Figure 40

Scenario 3U
Layer 7 Capture Zone
on VC Distribution

Tinker AFB, Oklahoma



▲ PR-2 Proposed Well Well ID

● TOR-7 R-7 83001 Extraction Well Well ID

Water Table Elevation Line Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 3

0° 22' TN MN 7.5° (1986)

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

1000 500 0 500 1000
FEET

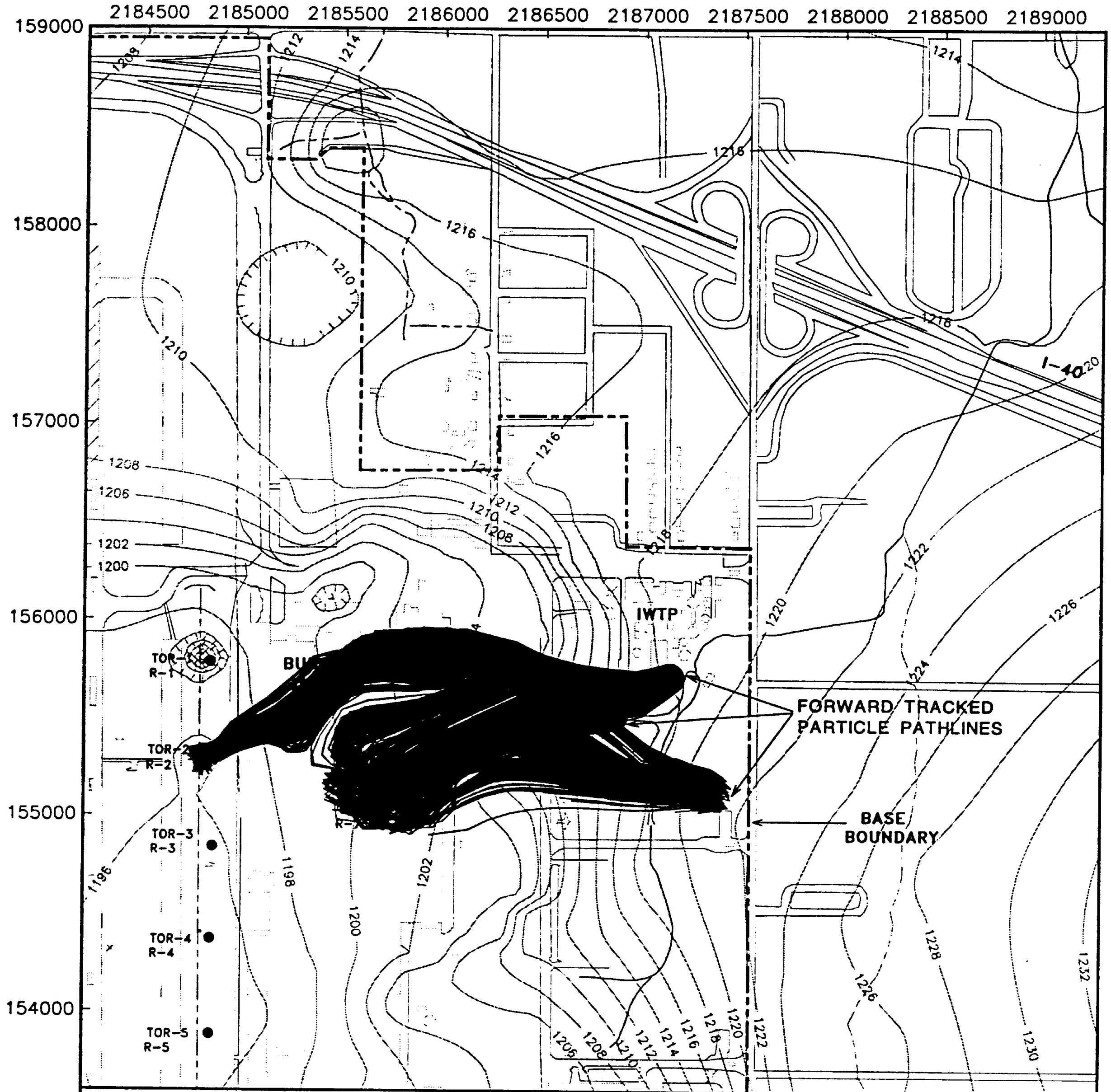
Figure 41

Task 2B Scenario 2
Forward Particle
Tracking From 1-50BR
LAYER 3

Tinker AFB, Oklahoma

File: 13vc.ps
Date: 7/29/96

BATTELLE



▲ PR-2 Proposed Well Well ID

● TOR-7 R-7 B3001 Extraction Well Well ID

Water Table Elevation Line
Contour Interval: 2 Feet
Perennial Stream
Intermittent Stream
Approx. Extent Layer 5

TN MN
0° 22'
7.5° (1986)

Projection Information:
Oklahoma State Plane Coordinate System
North Zone 3501

1000 500 0 500 1000
FEET

Figure 42

Task 2B Scenario 2
Forward Particle
Tracking From
1-50AR, 1-51AR, & 22DR
LAYER 5

Tinker AFB, Oklahoma

File: 15vc.ps
Date: 7/29/96

BATTELLE

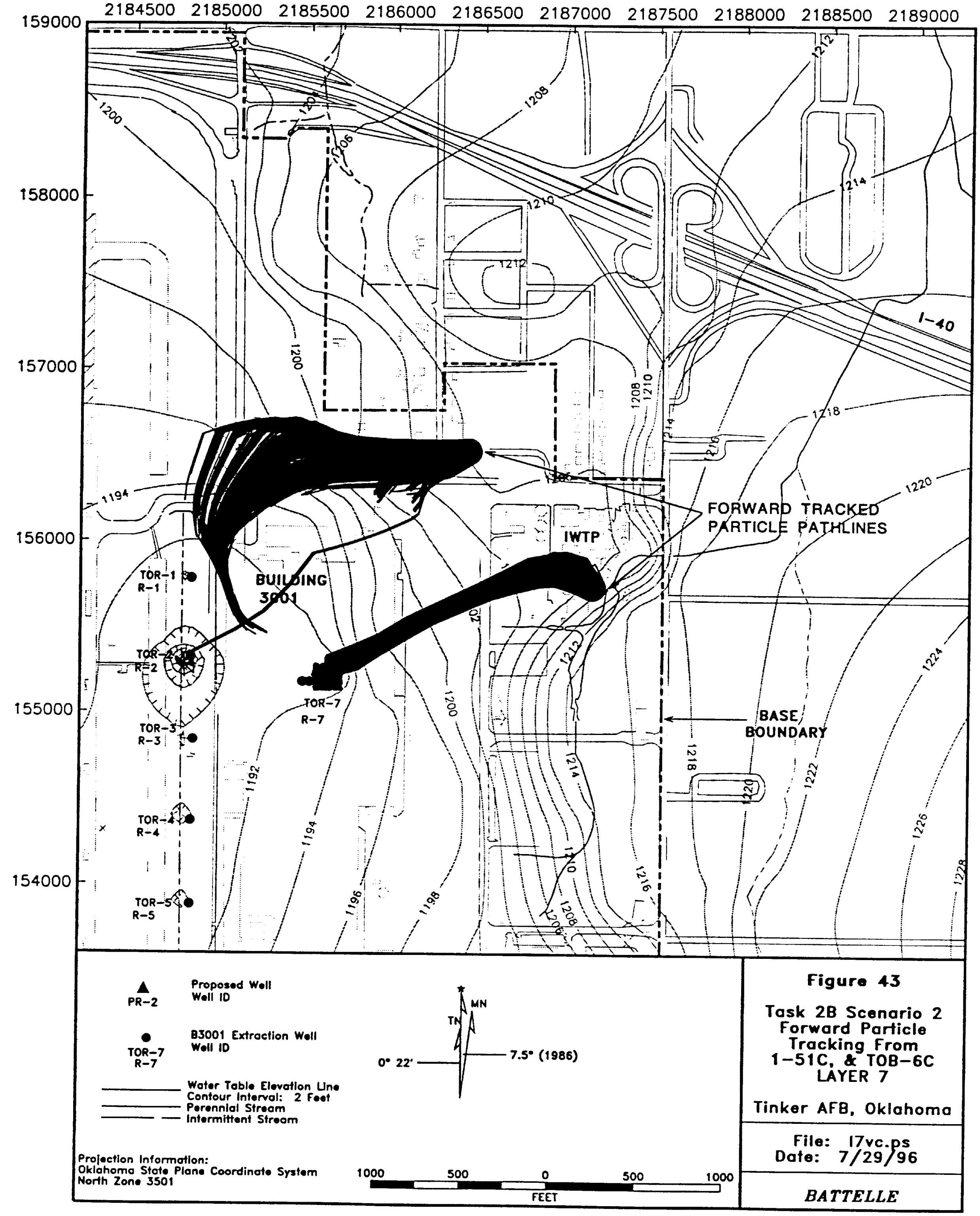


Figure 43

Task 2B Scenario 2
Forward Particle
Tracking From
1-51C, & TOB-6C
LAYER 7

Tinker AFB, Oklahoma

File: 17vc.ps
Date: 7/29/96

BATTELLE